Commemorating 50 Years (1967 - 2017)

50th Anniversary Celebratory Volume
Asian-Pacific Weed Science Society

Edited by:
Nimal Chandrasena
Adusumilli Narayana Rao

26th Asian-Pacific Weed Science Society Conference
(The Golden Jubilee Conference)
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Commemorating 50 Years, 1967 – 2017
Asian-Pacific Weed Science Society (APWSS)

"Weed Science for People, Agriculture and Nature"

".....To promote Weed Science, particularly in the Asian and Pacific Regions, by pooling and exchanging information on all aspects of Weed Science..."

50th ANNIVERSARY CELEBRATORY VOLUME

Edited by:

Nimal Chandrasena

Adusumilli Narayana Rao

Sponsored by:

Asian-Pacific Weed Science Society (APWSS)

Indian Society of Weed Science (ISWS)

The Weed Science Society of Japan (WSSJ)

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Section II - Memories and Reflections

Preface

The impetus for this 50th Anniversary Celebratory Volume of the Asian-Pacific Weed Science Society (APWSS) came from our firm conviction of the immense effort by the Society's founding fathers, and those who followed in their footsteps, to nurture the discipline in a way beneficial to the people and cultures in the Asian-Pacific region. After 50 years of existence, there is reason for the success of this 'interchange' of knowledge and association of like-minded people, to be celebrated. In this Celebratory Volume, with contributions from several members, we have attempted to contextualize the contributions of the APWSS, in terms of its origin and development, as well as its activities, which are firmly rooted in promoting the understanding of weeds and responsibly managing weed impacts with appropriate methods.

Not surprisingly, weeds have long been regarded as a major biotic constraint in agricultural production systems in the Asian-Pacific region, and also, globally. Negative impacts of weeds have also been felt and recognized outside agriculture, in forests, parks, nature reserves, waterways and other areas of human habitation. The threats posed by weeds have been considered severe enough to warrant the formation of several professional organizations to deal with weed problems, of which APWSS is one. The primary motivations to the founding of such societies have been to share knowledge on practical aspects of weed control - to achieve food security through the reduction of crop losses, and also lessen other negative impacts of weeds on the environment.

Realizing the growing threat of weed infestations in cropped and non-cropped lands, through the decades of 1950s and 1960s, scientists of the world had been undertaking research and sharing their findings on how to better manage weeds at various platforms. The need to collaborate and share knowledge led to the formation of professional Weed Science Societies in the 1950s. Most notable, would be the founding of two august bodies - the Weed Science Society of America (WSSA) in 1956[1] and the European Weed research Council (EWRC); the precursor to the European Weed research Society, EWRS) in 1960[2].

Tracing back the history of the APWSS, it was 50 years ago, in 1967, that our founding-fathers took the initiative to replicate the formation of an 'organization' of the Asian-Pacific Weed Science community into a forum that can efficiently facilitate an 'interchange' of ideas and information on matters related to weeds.

Coincidentally, the renowned British Crop Production Council (BCPC) was also formed in 1967, by the amalgamation of the British Weed Control Council and the British Insecticide and Fungicide Council[3]. In Canada, the *Canada Weed Committee* – the precursor to *The Canadian Weed Science Society,* was constituted as a 15-member, government-appointed entity in 1968[4]. In India, the *Indian Society of Weed Science* (ISWS) was also formed in 1968[5].

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1 Weed Science Society of America (WSSA); http://wssa.net/society/society-information-2/

2 European Weed research Society (EWRS) History; http://www.ewrs.org/history.asp

3 British Crop Production Council (BCPC) https://www.bcpc.org/

4 The Canada Weed Committee was renamed in 1978 as the 'Expert Committee on Weeds'; 25 years later, The Canadian Weed Science Society was formed in 2002; http://weedscience.ca/history/

5 The Indian Society of Weed Science (ISWS); http://isws.org.in/

In Australia, the first weed control conference was held way back in 1954; however, the Weed Society of New South Wales – claimed to the oldest Weed Society in Australia, was formed in 1966[6]. Heady days, indeed, they were, for optimism, collaboration and promotion of the exchange of ideas, information on weed control and its basic science – *Botany*.

It is significant that the APWSS arose primarily under the auspices of the East-West Centre in Hawaii with support from the University of Hawaii, Honolulu[7]. Engagement with the Asian-Pacific region, in all fields of endeavour, including agriculture, was US Government policy at that time. History shows that many developing countries benefited from the relatively benign geo-politics of the era and overseas development assistance, particularly directed towards the Asian-Pacific region by USA, through the East-West Center.

The birth of the APWSS also has to be historically viewed as an effort by our predecessors to provide a platform for ongoing '*friendships, liaison and improve lines of communication*', across local, regional, or intercontinental boundaries, and fulfil the need to join hands with others, for a common cause.

The impetus given by American weed scientists in 1967 for the dialogue to commence is evident in the list of participants of the first 'interchange' (51 out of 87) and the countries, which were represented at the meeting[8]. For posterity, we republish the following, which are excerpts from a previous Presidential Address of a founding member – Dr. Kenji Noda of Japan[9]:

> *"…In 1967, the First 'Asian-Pacific Weed Control Interchange' was called to order in Hawaii, USA, under the chairmanship of Dr. Y. B. Goto, and the co-chairmanship of Dr. H. F. Clay, Dr. R. R. Romanowski, and Dr. D. L. Plucknett. At the final meeting of this interchange, it was decided that the Asian-Pacific Weed Science Society begins with all delegates present and the interchange be designated the First Asian-Pacific Weed Science Conference.*
>
> *In 1969, the second conference was held at the International Rice Research Institute, in the Philippines, under the presidency of Dr. M. Vega. The third (conference) was in Kuala Lampur, Malaysia, in 1971, under the presidency and chairmanship of Dr. C. Van der Schans and Dr. D. E. Barnes, respectively. The fourth conference was convened by Mr. L. J. Matthews in 1973, at Rotorua, New Zealand. During the time from 1971 to 1973, constant efforts were made by the past president, Mr. L. J. Matthews, to establish the Asian-Pacific Weed Science Society, as a scientific society. At that time, rules were established for the society, the publication policy for conference proceedings were set in the right direction, the allocation of responsibility of the Executive Members and Area Convenors were agreed upon, and so on…"*

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6 The Weed Society of New South Wales; http://www.nswweedsoc.org.au/

7 APWSS (1967). Proceedings of the First Asian-Pacific Weed-Control Interchange. "Weed Control Basic to Agriculture Development" (Eds. R. R. Romanowski, Jr., D. L. Plucknett and H. F. Clay). Asian-Pacific Interchange. East-West Center, University of Hawaii, Honolulu, Hawaii (June 12-22, 1967). pp. 141.

8 Breakdown of original 87 participants at the inaugural APWSS by country: USA (51); Japan (11); Philippines (4); Fiji (3); Republic of China (ROC), Taiwan (3); Indonesia (2) New Zealand (2); New Caledonia (2); India (2); Malaysia (1); Thailand (1); Pakistan (1); Hong Kong (1); Tonga (1); New Guinea (1) and United Kingdom (1).

9 Noda, K. (1975). Presidential Address. Proceedings 5th APWSS Conference, Tokyo, Japan, 5-11 October. 1-3.

We believe that since its birth on 22 June in 1967, at the Prince Kuhio Hotel on the Hawaiian Island of Kauai, USA, APWSS has grown and developed into a major, regional and international Weed Science Society. As with any group, diverse in culture and economies as in our Society, achievements have not come automatically and consistently. During the past 50 years, APWSS has had its ups and downs, because it relies heavily on its Executive Committee, individual members, affiliated societies, and their commitment to the Society's objectives. In our view, diligent efforts of some active national societies and individual members have helped to maintain the momentum of the Society.

Nevertheless, the proof of on-going success of the APWSS lies in 27 well-attended Conferences and information-filled proceedings, books, workshops and other exchanges. We believe that the added attraction of enrichment of one's outlook by visiting different countries, which host the Conference, has also been a contributory factor for APWSS's success. In a Plenary Address, at the 12th APWSS Conference, in Seoul, Korea, the Founding President, Marcos Vega (1989)[10] showed confidence that even in the first 22 years of its existence APWSS had made an impact in the region with regard to leading and co-ordinating the efforts of exchange of weed control information:

> *"…Why do members of a Society devote precious hours to organizing and convening conferences? The answer revolves around need – A need for linkages, whether local, regional, or intercontinental – A need to share information, experimental results, problems, answers… The data on the number of scientific papers presented; the numbers of registered participants and the venues of the conferences all point to a viable and relevant organization. No Society, scientific, or otherwise, would have lasted as long as the APWSS has – if it was not serving a useful purpose…"* Vega (1989)

Over the years, the discipline of Weed Science, as well as professional societies in the Asian-Pacific region developed relatively slowly. As discussed by contributors to this Volume, several professional 'Weed Societies' in our member countries were formed only after the APWSS, with some exceptions[11].

APWSS has been providing a major platform for these regional Weed Science Societies for organizing the APWSS Conferences every two years. The list of previous Conferences, organized in different countries of the Asian-Pacific Region, and specific details on dates and venues, have been provided by several authors in subsequent Chapters of this Volume. Briefly, the countries, which hosted the Conferences are as follows: Philippines (1969, 1983 and 2003); Malaysia (1971 and 1997); New Zealand (1973); Japan (1975; 1995 and 2017); Indonesia (1977, 1991 and 2013); Australia (1979, 1993 and 2011); India (1981 and 2015); Thailand (1985 and 1999); Hawaii (1st 'interchange' Conference, 1967) Taiwan (1987); South Korea (1989); China (2001); Vietnam (2005); Sri Lanka (2007) and Pakistan (2010).

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[10] Vega, M. (1989). A Glimpse of the Past and Suggestions for the Future. APWSS Plenary Address. pp. 613- 617, Proceedings Vol. III of the 12th Asian-Pacific Weed Science Society Conference, 21-26 August 1989, Seoul, Korea.

[11] Exceptions were the American Society (WSSA, in 1956); and the 'Weed Society of Japan', which had been established in 1962. The Japanese Society later became the 'Weed Science Society of Japan" (WSSJ) in April 1975. With regard to affiliation of member country societies with the APWSS, Philippines (1969), Malaysia (1971), Indonesia (1971/72), and New Zealand (1973) were the first countries, followed by Japan and Thailand, both around 1975. In our view, although the Indian Society for Weed Science (ISWS) had been established in 1968, active affiliation of ISWS with APWSS may have occurred only over the ensuing 1970s decade.

In 2017, after 50 years of existence, APWSS is celebrating its Golden Jubilee, as it holds its 26th Conference at Kyoto, Japan. The hosting of the Conference in Japan, one of the founding members and major contributors to Weed Science in the region, should not go unnoticed.

In this 50th Anniversary Celebratory Volume, we have contributions from several eminent weed scientists, by way of contributed technical papers, joyful memories and thoughtful reflections. This volume adds to the previous treatise, produced by APWSS in 2015 (celebrating the 25th 'Silver Jubilee Conference'), which reviewed the current status of Weed Science in each of the member countries[12]. We believe that these publications are unique in that they provide data, overviews and practical information on weeds and their control in our region for the interested reader, along with perspectives on historical developments of the discipline of Weed Science in the Asian-Pacific region.

As Editors, we thank each and every one of the authors who laboured on the task and contributed to the Volume. Each, in his or her own way, has contributed to making this Volume a useful treatise for future generations to look back upon. The contributors include several Past Presidents of the APWSS – Dr. Steve Adkins (Australia); Dr. Aurora Baltazar (Philippines); Dr. Peter Michael (Australia); Dr. Duong Van Chin (Vietnam); Dr. N.T. Yaduraju (India); Dr. Buddhi Marambe (Sri Lanka); Dr. Denny Kurniadie (Indonesia) and Dr. Khan Bahadar Marwat (Pakistan). Their experience of past APWSS experiences and thoughtful reflections provide different perspectives on the APWSS journey, its history and evolution.

We are grateful that Dr. Raghavan Charudattan looked into the future of biological control of weeds. Similarly, Dr. Nilda Burgos and a group of colleagues have reflected in detail on the likely impacts of molecular biology and genomics on the evolution of the discipline. Emerging weed scientists – Dr. Asad Shabbir (Pakistan), Dr. Puja Ray (India) and Dr. Khawar Jabran (Pakistan) provide interesting perspectives on what they consider important in the future of Weed Science in our region.

One of our Past Presidents, Dr. Peter Michael from Australia, has graced this Volume with the latest key to separate barnyard grass (*Echinochloa* species), a particularly bothersome weed in the Asian-Pacific Region. Dr. Michael is renowned in our region for his expertise and dedication to plant taxonomy and his life-time of contributions to resolving the taxonomic issues of barnyard grass are revealed in this illuminating paper.

Other luminaries - Dr. Hirohiko Morita (Japan); Dr. Kazuyuki Itoh (Japan), Dr. K.U. Kim (Korea) and Dr. Surajit De Datta (USA) have provided useful reminders on how the Society evolved, highlighting their own research, and involvements. The contributions of other APWSS members: Dr. A.R. Sharma (India); Dr. A.S. Juraimi (Malaysia); Dr. Hazrat Ali (Bangladesh); Dr. B. Chauhan (Australia); Dr. C. Maneechote (Thailand) and Dr. Gul Hassan (Pakistan) provide useful recollections and their memories of association with the APWSS. These contributions also highlight the influence APWSS has had on individual member countries.

In our own paper (Chapter 1), we took a critical look at the history of the APWSS and events, which may have fashioned its activities and membership. We reflected on the origins and the past and challenges of the Society, and focused on aspects on how to improve the outlook and future activities of the APWSS. We are strong believers in understanding history, because it helps us understand how and why we have

[12] Rao, V.S, Yaduraju N. T., Chandrasena, N. R., Hasan, Gul and Sharma, A.R. (Eds). (2015). *Weed Science in the Asian-Pacific Region*. An Asian-Pacific Weed Science Society publication. Indian Society of Weed Science, Jabalpur, India. 389 pp.

done things the way we did; and also to learn from perhaps the mistakes of our predecessors, so that we may do things better.

That this Society would take an inclusive approach to what constitutes the broad field of Weed Science is without any doubt. For instance, it will continue to promote a better understanding of both human and weed impacts, without exclusion. It will also promote all aspects of weed control within the paradigms of landscape management, integration of weed management with the work of allied disciplines, such as holistic farm management and ecosystem restoration.

Within the context of an inclusive approach, the Society would be open to researchers from all traditions, as long as long our research uses rigorous methods; is focused on improving weed management; and aims at knowledge that can be transferred across settings. We are hopeful that the Society would be attractive to scientific researchers who are associated with herbicide research, but also to other disciplines, such as plant physiology, entomology, genetics, plant breeding and evolution.

A Society, such as ours, would need fruitful collaboration with related societies and organizations, which may include having combined meetings. Special links may be developed with one or more journals. Finding a home for the APWSS Website and maintaining it to provide a 'voice' for Weed Science in the region, disseminating information on relevant resources, events, and training opportunities is an utmost priority for the Society. We hope that the enthusiastic voice emanating from the 50th Anniversary Conference will be heard by funding agencies, political arenas, and similar institutions.

When we proposed the idea of a Celebratory Volume in October 2016, and eventually undertook the task in December 2016, it was also the time to 'take stock' of APWSS matters, including its strengths and weaknesses, which became apparent during the past 12 months. An organizational structure and financial resources are required to develop and run a Society, such as ours. As Editors of this Volume, our aim is to continue the conversation further, to discover if we can establish a shared vision across academics and stakeholders, engaged in creating scientific knowledge on how to improve Weed Management.

Our contributors have raised some interesting issues, not least of which is the issue of poor communication within the Executive Committee, affiliated Societies of member countries, and the general membership. We agree this is a matter that has caused some anxiety to us, even when we undertook this editorial exercise. Several contributors have also pointed to the need to put APWSS on a firmer financial footing, so that its activities can be expanded. Suggestions include exploring the possibility of having APWSS's own journal, taking advantage of the 'on-line' access platforms, which are readily available. Future Executive Committees will have to work hard on these challenges, within the socio-cultural milieu of the Asian-Pacific region.

Finally, as Editors, we are grateful to the current President, Dr. Hiroshi Matsumoto, for supporting this Celebratory Book initiative; and Dr. Hirohiko Morita, who has made a generous contribution towards the printing of the Volume. We also wish to acknowledge the support of others, particularly, the Japanese Local Organizing Committee of the Golden Jubilee Conference, for the important role they played.

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16 July 2017

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President's Message

Hiroshi Matsumoto[13]

As the current President of the Asian-Pacific Weed Science Society (APWSS) I am delighted to pen this message for this 50th Anniversary Celebratory Volume.

This year (2017), APWSS is celebrating its 50th Anniversary of existence. As the current President of the Society, it is indeed a great honour for Japan and personally for me to host the 50th Anniversary Memorial Conference (which happens to be the 26th APWSS Conference) at Kyoto, Japan. It is also with great pleasure that I acknowledge the Local Organizing Committee of APWSS, which is co-hosting this event with support from the Weed Science Society of Japan (WSSJ) and members of the APWSS Executive.

Weed Science has now evolved to be a comprehensive field of science with research areas that cover multiple scientific disciplines, such as ecology, biology and chemistry, related to weeds and their management. Weed Science is nowadays an advanced science that is closely linked to human societies. However, in recent years, the problems of weeds seem to have become more serious. Especially, herbicide resistant weeds are now found in 80 countries in the world and this problem is causing major economic impacts in several countries of Asian-Pacific region, as well. Hence, information sharing and collaborative research among weed scientists of our region becomes more and more important. We should use interdisciplinary and multi-faceted approaches to address future weed management. To achieve this, it is my fervent wish that APWSS will function as a core organization for the Weed research community of the Asian-Pacific region.

APWSS Conferences are held every two years in different, affiliated countries in the Asian-Pacific region. The two year cycle is a relatively short interval, compared with other international conferences. However, this two year cycle provides good opportunities for the young researchers and students to present their research at an international forum and also to become familiar with different cultures. It is essential for the APWSS Executive to take necessary policy decisions that makes young researchers 'participation easy'.

To strengthen the APWSS Conference as a place of promotion of mutual interchange and acquire experience for young researchers, the Conference should be of high quality in content and well-organized. We, as the Local Organizing Committee of the current 26th APWSS Conference, have worked long and hard in our effort to organize the conference, aiming for high scientific quality and organization.

Regarding my own experiences at APWSS Conference, I participated for the first time at the 10th APWSS Conference in Chiang Mai, Thailand during 24 to 30 November 1985. At that time, I was in Bangkok as an expert of the Japan International Cooperation Agency (JICA), and gave support to setting-up the radioisotope research facility in the Department of Agriculture in Thailand. Since 1985, I have been participating in the APWSS Conferences and presenting our research, particularly on modes of action of herbicides and on natural compounds, which show plant growth regulating activity.

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Of course, one the most impressive and important conference for me personally was the 15th APWSS Conference held in Tsukuba, Japan during 24-28 July, 1995, for which Professor Kozo Ishizuka was the Chairman. I was forty years old at that time and served as one of members of secretarial team in the local organizing committee. The 15th APWSS Conference was attended by 428 participants from 24 countries and 179 presentation were made, including five plenary lectures.

The experience of that time greatly helped me to develop my administration and organizing skills, which I have applied to organizing the current 50th Anniversary Conference. At this 26th APWSS Conference, we would like to get more participants and presentation than at the 15th APWSS Conference, held 22 years ago, in Japan.

In the preparations for this 50th Anniversary Conference, we received a lot of assistance from many people and organizations, including APWSS Members and seniors. I thank them all and the contribution from the foundations and private sectors. In addition, members of the International Organization Committee gave much advice and support to us.

Especially, we are grateful Dr. A. N. Rao (current General Secretary, APWSS) and Dr. Nimal Chandrasena (former, General Secretary, APWSS, 2010-11) for their devoted support. I also thank them for their original idea and tireless effort as Editors in bringing out this 50th Anniversary Celebratory Volume with so many impressive contributions from various members. I believe that this Volume will go down in APWSS's history as another landmark contribution of ideas and exchanges of Weed Science-related knowledge and information from our region.

Finally, I thank Dr. Hirohiko Morita, Japan, one of our senior members, for his generous financial contribution towards the printing of this Celebratory Volume.

Dr. Hiroshi Matsumoto
President, APWSS (2016-17)
10 July 2017

Section I :
Contributed Papers

Asian-Pacific Weed Science Society: A Glimpse of the Past 50 Years and Perspectives

Nimal Chandrasena[14] **and Adusumilli Narayana Rao**[15]

Abstract

Since the mid-1940s, exciting discoveries of new herbicides led to noticeable improvements in weed control in many crops over the following two decades, leading to yield increases. However, the optimism of achieving weed control through herbicides alone was short-lived. The harmful effects caused by an overuse of chemicals were felt through the 1950s, igniting the need for ecological thinking to understand weeds *prior* to their control. This is why Weed Science took an important change in direction in the late-1950s to encompass studies of weed biology and, ecology - to anchor the evolving discipline in a broader agro-ecological context. As the World's population increased dramatically in the 1960s, in the Asian-Pacific region, there was a deeply-felt need to improve weed control to increase food production. In 1967, the Asian-Pacific Weed Science Society (APWSS) was born to *promote an exchange of ideas on weed control* across the region, including the use of herbicides.

The period of *ecological enlightenment* (1960 to 1975) led to weeds being understood as 'colonizing species'. Colonizing species opportunistically capture resources created by habitat disturbances caused naturally, or by human activities. The placement of weed studies within this ecological framework broadened the discipline to include sustainable weed control practices promoted through the vehicle of Integrated Weed Management (IWM). As a result, discourses in Weed Science, including those at the APWSS, from around the late-1980s, expanded to cover biological and ecological aspects of weeds, as well as mechanisms of crop-weed interactions (i.e. competition, allelopathy, and critical weed-free periods). This trend has continued in recent decades, causing a paradigm shift - *from herbicide dominated weed control to Weed Science*.

In more recent times, research in the Asian-Pacific region has focused on reducing a dependence on herbicides, in favour of integrated weed management (IWM). Management of herbicide resistance in weeds; understanding the potential impacts of climate change and genetically-modified organisms (GMOs) in agriculture; and special weed problems, such as weedy rice, dominate the APWSS research agenda. Reducing conflicts between weeds and men, through a recognition of the redeeming value of weeds and utilization of weeds as bio-resources are also emerging as topics of interest. In our time, when the need to increase the output of food for the rising population of the world is acutely felt, and interlinked human impacts on the globe are accelerating, the scope of Weed Science cannot but expand. The major challenges humans face in this second decade of the 21st Century will encourage us to deeply reflect on our relationship with weeds. We hope that Weed Science will help us learn from weeds that 'co-existence' and austerity are virtues for the future survival of our species.

Keywords: Herbicides; Asian-Pacific Weed Science Society; weed control; Weed Science.

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Introduction

Agricultural production losses due to pests, diseases, and weeds can be substantial, although estimates of such losses are difficult to obtain, and vary much across countries of the Asian-Pacific region. The adverse effects of pests, diseases, and weeds are greatly influenced by local agronomic and climatic factors in different countries, and by the local, socio-economic factors, operating within their production systems. While many factors cause losses in agricultural production, there is little doubt that weeds are a major concern. However, because weeds are so common and widespread in the Asian-Pacific 'tropical' region[16], together with a few temperate countries, their significance in terms of causing production losses is not well appreciated. The economic costs of weeds in most of the Asian-Pacific countries are also not well known, although estimates exist for specific crops in some countries. For example, the well-known Australian study (Sinden *et al*., 2004) estimated total losses in Australia, due to weeds to be about Aus $4 billion/year. In India, even with conservative estimates of average 10% losses in any crop, Yaduraju (2012) suggested that loss of food grain yield, attributable to weeds would far exceed US $ 13 billion/ year.

However, in many situations, the negative impacts of weeds are not perceived to be as dramatic, as those caused by pests and plant diseases. Some of the pioneers of Weed Science considered weeds only as 'nuisances', and that too, only when they are 'very abundant' (see Harper, 1960). In a similar vein, we could excuse farmers, particularly in our region, for considering weeds as just another annoyance, without much consideration for economic losses they may cause. In fact, many societies and cultures of our region consider weeds to be useful allies recognizing their redeeming values (see Chandrasena, 2007).

In our view, most chemical weed control methods evolved, through the past 50 years or more, without the full knowledge of the weed related losses that can be prevented. There is not much understanding of what weeds really are, or their role in nature. However, weed scientists, with an ecological-bent, have been long aware that weeds are only '*colonizing species*' (defined as *plants or animals that find themselves in a new locality, confronted by challenges of a new environment; and therefore, pioneers in that environment*) and weed problems persist because of favourable environments created for their proliferation by modern agricultural practices and other disturbances[17].

The Asian-Pacific region and countries cover a wide geographical area, with diverse landscapes, climates, cultures, economies, and agriculture systems. They include countries of South Asia, East Asia, South-East Asia, West Asia, and Oceania, including New Zealand, Australia, Fiji, and the United States. In 1967, the Asian-Pacific region's population was 3.461 billion; in 2017, it is now 4.478 billion. The region, therefore, accounts for about 60% of the current world population of 7.511 billion[18], while occupying just 37% of the Earth's land mass and 48% of the global arable land. Seven of the 10 most populous nations in the

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[16] The founding fathers of APWSS deliberately targeted stimulating Weed Science and weed control in the 'tropics', through the Society, giving major attention to rice, coconuts and other crops, because weeds were roughly estimated to 'stifle' as much as 40% of production in the tropics (APWSS, 1977; APWSS 1988).

[17] Ecologically speaking, Bunting [1960] referred to weeds as '*pioneers of secondary succession*'. Baker [1965] defined a weed as '*a plant …if, in any specified geographical area, its populations grow entirely or predominantly in situations markedly disturbed by man, (without, of course, being a deliberately cultivated plant)*'.

[18] http://www.worldometers.info/world-population/population-by-country/ (Accessed 19th June 2017).

world are in this region (i.e. China, India, USA, Indonesia, Pakistan, Bangladesh and Japan), accounting for more than half of the global population. This region includes some of the oldest civilizations and culturally rich countries in the world. It also accounts for four of the top 10 global economies (USA, China, Japan and India), and 58% of world's GDP, which can also be regarded as the 'powerhouse' of global science and technology and human ingenuity.

The Asian-Pacific Weed Science Society (APWSS) came into being following an "*Asian-Pacific Weed Control Interchange*", held during 12-22 June 1967 at the East-West Center, University of Hawaii, in Hawaii. A group of 87 individuals, from 22 countries, participated at the inception meeting under the theme: "*Weed Control - Basic to Agriculture Development*". On the last day, a Workshop recommended the formation of an organization: "…*to facilitate the interchange of current weed control information and promote research in Weed Science...*" The primary motivations for founding the APWSS become clearer in the words of one of our founding fathers - William Furtick (1969):

> *"…Weed Science suffers because weeds have been an integral part of agriculture from the beginning and their damage is less dramatic than that caused by insects and diseases. However, it is apparent that weed control is a pre-requisite for the development of modern agriculture, which is based on developing high yielding, high quality varieties that can produce their potential only under optimum fertility, water and freedom from pests.*
>
> *This means that without weed control, modern agriculture will end up under a canopy of weeds. It is the duty of the weed societies to get this story across to others in agriculture. It has often been possible for the representatives of industry to convince the farmer whose income is affected, while professional agriculturist is oblivious to this basic importance of weed control. This cannot continue, but can only be changed by a planned effort…"*

Scientific societies serve many purposes. They are conduits for information and provide networking opportunities for their members. Societies are often important lobbying organizations that make sure that governments regularly hear scientists' perspectives on various scientific issues. Regional societies, such as the APWSS, made up of a number of affiliated, national societies of individual countries provide opportunities for wider exchanges and interactions, across those countries. As our founding fathers imagined, the Society provides the foundation for the '*planned effort*' (Furtick, 1969) and coordination on which the platform can be built, making weed scientists of the region feel that they '*belong*' to a worthwhile community, through knowledge sharing. They also play a critical, peer evaluation role of scientific claims being made.

Over the years, the discipline of Weed Science has also developed in many countries of the Asian-Pacific region, but the pace of that development has varied widely. Professional scientific societies dealing with weeds and weed control have been widely established for mutual exchange and sharing of knowledge. Besides organizing conferences, symposia and other activities at the national level, these societies have also provided important settings for sharing of international experiences on emerging issues in Weed Science.

Given the importance of the region on a global scale, in this 50th Anniversary year of the APWSS, in this paper, we cast our eyes on the *World of Weed Science*, prior to the 1967 founding of the Society to understand the social milieu in which our founding fathers operated, and the platform on which the

Society was built. We also review prior events, the evolving state of knowledge about Weed Science, which form the foundation upon which the APWSS has been built, for the benefit of the region.

We are aware that our interpretations of history are shaped by our own background and experiences, which may be different to the perceptions of others. Nevertheless, we regard this as an opportune moment for deeper reflection. Understanding the historical context in which APWSS was born is critical to planning the directions for its future. Understanding some of the challenges we face within the discipline of Weed Science will assist APWSS to move its scientific enquiries and endeavours in directions that may better suit our region, its growing population and food production needs, whilst protecting limited natural resources and the fragile environment. To this end, as we celebrate 50 years of APWSS existence, we also offer a summary of major highlights, an analysis of significant events, and a broad overview of the Society's contribution to Weed Science in the region.

In capturing the essence of APWSS's impact on matters related to weeds and their control, we hope its value in the region is better understood. Notwithstanding the challenges ahead, we hope that our interpretations and perspectives will assist further developments in Weed Science in the region, as well as stimulate the Society to grow further, over the next 50 years!

Development of 'Weed Science' – through the Lens of History

Although weeds have interfered with human activities since recorded time, as a discipline, Weed Science was slow to develop. The first humans, our hunter-gatherer ancestors, hunted animals and searched for edible plants. When some humans accidentally discovered that they could deliberately grow food crops, they settled in one place, beginning the journey of agriculture, around 10,000 to 12,000 years ago.

Within a few millennia, humans also realized that the production of the crop of their choice, mostly, coarse-grain cereals, was greatest when that crop grew in the absence of competing, inedible species, which grew in the same habitat, around their dwellings. Our ancestors would have manually removed such species, releasing their crops from weed competition. "Slash and burn" agriculture, still used widely in developing countries, was also an early attempt at reducing weeds in areas of habitation that were converted to cultivation. After several millennia of settled agriculture, Bronze Age humans (approximately, 3,500-1,000 BC) appeared to have understood the concepts of growing crops as monocultures to obtain higher yields; expanding cultivated areas along the river deltas to capitalise on seasonal flooding and reduce yield losses due to weed competition.

However, in those early millennia, humans managed weeds with bare hands, or sharp sticks, long-handled tools with a flat blade made up of rudimentary iron or bronze (hoes, mamoty). Human labour was cheap and readily available, including slave labour, right up to modern times. Use of metal tools for weed control, occurred first in the Bronze Age, and expanded later, in the Iron Ages (approximately, 1,000 BC to about 1,000 AD). Historical records, such as Egyptian art and hieroglyphics, preserved in the pyramids, show that ancient civilizations, up to at least 3,500 BC used animals (bulls, buffaloes, and horses), to pull ploughs for tillage, and concurrently, achieve weed control. Animal power supplemented human labour as an essential part of ploughing and weed control for millennia, and continue even today in many Asian-Pacific countries.

[19] A history of Weed Control in the United States and Canada by F. L. Timmons was originally published in *Weed Science*, 1970. 18 (2): 294–307). It has been republished in 2005 - *Weed Science*, 53: 748-761.

In tracing the history of Weed Science in the USA and Canada, Timmons (2005)[19] concluded that relatively few agricultural leaders and farmers became interested in weeds as a problem before 1,200 A.D. or even 1,500 A.D. For several millennia, weed control was incidental to tillage for land preparation, growing and cutting, or pasturing of thickly planted crops. An English farmer, Jethro Tull (1762)[20], then invented row cropping, permitting 'horse-drawn hoeing' whilst controlling weeds through cultivation. The steam-driven tractor, invented in the mid-19th Century, then replaced the horse. During the early part of the 20th Century, fuel-driven tractors were built in both Europe and USA, making large-scale ploughing and land preparation possible, simultaneously achieving weed control.

However, as traced by historians – Clinton Evans (2002) and Zachary Falck (2010) until the mid-20th Century, crop losses, due to weeds, were considered '*manageable*' with some effort, and mostly ignored, while research efforts in agriculture focused mostly on the control of plant pathogens and insect pests that caused spectacular, and large-scale damage to crops.

A review of literature indicates that Entomology and Plant Pathology had been disciplines for nearly a century before Weed Science became an important subject. In our view, early farmers *accepted* a relatively constant, predictable, crop yield loss from omnipresent weeds. In contrast, as Burnside (1993) pointed out, '*Weed Science developed as a Step-child*' and impacts of plant pathogens and insect pests were conceived as more devastating and unpredictable, although losses caused by those organisms varied greatly from year to year.

It appears, historically, that farmers were most concerned by the *unpredictable* losses from pests, other than weeds. Perhaps a relatively benign attitude towards weeds prevailed at least within some sections of the society in North America, as evident in the following stanza, written by a famous American Poet – James Russell Lowell (1848):

> *"…One longs for a weed, here and there, for variety; though a weed is no more than a flower in disguise, which is seen through at once, if love give a man eyes..." A Fable for Critics (1848)*

Ralph Waldo Emerson's famous quote, made in a speech in 1863: "…*What is a weed? A weed is a plant whose virtues have not yet been discovered…*" also shows that sections of the American society had no qualms about boldly expressing the positive aspects of weeds (Emerson, 1863; also see Chandrasena, 2015).

We would add that most Asian-Pacific societies evolved with similar, but more than a relatively benign attitude towards weeds. Many cultures in our region have valued weeds for millennia for a variety of uses. Until herbicides were introduced in the 1960s, 70s and 80s as the panacea for obtaining higher crop yields, many societies did not consider weeds as enemies, and were willing to accept some losses due to weeds as inevitable. In making this point, we emphasize the fact that much of the great strides in improving food production in those decades, pre- and post- "Green Revolution", was largely due to a combination of improved cultivars, fertilizer use, more holistic crop protection and other agronomic practices, and not just herbicide use.

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[20] Tull, Jethro (1762). Horse-Hoeing Husbandry or An Essay on the Principles of Vegetation and Tillage. Of Weeds, Chapter VII, p. 73. (http://www.archive.org/details/horsehoeinghusba00tull).

The *human-weed conflict*, which has been concocted and marketed as a '*War with Weeds*', is unfortunate, and its effect has been pervasive, much to the detriment of proper scientific inquiry within Weed Science. The needless '*us-and-them*' narrative began very much in the last two decades of the 19^{th} Century, and the blame must be attributed to attitudes at that time, prevalent in North America, invaded, and settled largely by people of European descent (see Evans, 2002; and Falck, 2010).

Weed Science, as a discipline in agriculture, first received significant national recognition in USA only in the mid-1940s (Burnside, 1993). Bolley in the USA, Bonnett in France, and Schultz in Germany, around 1900, independently, found that solutions of copper salts, used for controlling plant diseases, would selectively control broadleaf weeds in cereals (see Timmons, 2015). This led to the use of copper sulphate and other chemicals (sodium borate and sodium arsenate), for selective weed control in the first decade of the 20^{th} Century, ushering a new beginning for weed control, which was not possible until that time.

Following on, the almost simultaneous discovery of herbicides: 2, 4-D (2, 4-dichloro-phenoxy acetic acid) in the USA, and MCPA [(4-chloro-2-methyl-phenoxy) acetic acid] in England, during 1941-42 revolutionized the field of weed control. For the first time in history, around 1944, the selective activity of these auxin-like herbicides in controlling broad-leaved weeds in grass turf was demonstrated in the USA and UK, leading to much excitement and the release of the first commercial herbicides (see Duke, 2005).

The post-World War II period saw a great deal of interest in the possibilities of applying chemical solutions - organic compounds, that could selectively destroy weeds across large landscapes, thereby saving labour, which would otherwise be spent on weed control. The fact that herbicides could be economically synthesized in bulk, on an industrial scale, galvanized industry, adding to the excitement of discovery and development. The period of 25 to 30 years after the end of World War II is regarded as the *'Golden Age of Herbicides'*, and as Duke (2005) pointed out, the cost of discovery and registration was not prohibitive at that time, so even small companies made profit from new discoveries and got involved in weed research.

However, the demonstration of efficacy with which herbicides could control weeds also narrowed the focus of enquiry, leading to the skewing of Weed research in favour of herbicides, and the somewhat glamorous research on 'Mode of Action' of herbicides. On the positive side, the mode of action research led to strong interactions between weed scientists, plant physiologists, and biochemists, both within industry and outside, perhaps working so closely for the first time. The joint research between the industry scientists and academics led to major findings on the mechanisms of uptake, translocation, biochemical pathways, and metabolism of chemicals within plants. Some of this weed research, such as those on photosynthetic inhibitors, revolutionized the field of Botany and our understanding of how plants function.

A Glimpse of the Past – Pre APWSS Influences

In the APWSS 40^{th} Anniversary publication, Baltazar (2007) referred to several significant events (see below), which may have influenced the developments of Weed Science in the Asian-Pacific region:

- **Before 1960-Start of Chemical Control** Herbicides were introduced into the region; auxin-herbicides (2, 4-D, MCPA), amides (butachlor), carbamates (thiobencarb), dinitroanilines (trifluralin), etc.

- **1960-Green Revolution:** The development of "Miracle Rice" and "Mexican Wheat"; high-yielding varieties (HYVs) of rice and wheat, largely, short-statured cultivars, replacing tall, traditional cultivars, signalled the start of the 'Green Revolution' and the doubling of crop yields. The introduction of HYVs emphasized the critical role of weed control.

- **1970-Shift from Transplanting to Direct-seeding:** Rice cropping increased from one crop per year with transplanted rice, to 2-3 crops with direct-seeded rice (DSR) cultivation, again increasing yields. The water regimes changes in DSR favoured moisture-loving grasses, shifting the major weed problems in rice from broad-leaf weeds to more difficult to control grasses.
- **Changes in Pest (Weed) Control Paradigms:** The change in the crop protection paradigm to more holistic integrated weed management (IWM) in cropping systems, incorporating cultural, biological, and chemical control strategies for major weed problems.

We essentially agree with those sentiments. Our review of APWSS literature also finds that herbicide-based weed control was a key component, and perhaps even *the driving force* for establishing the APWSS as a Society 'promoting linkages' across industry, farmers and academics. However, a nuanced understanding of history would indicate *it was not the only factor*. We believe our predecessors would have been influenced by various events and initiatives, which preceded the founding of the Society. Other motivations, such as which weed species were making the biggest impact across the region; obtaining a good understanding of weeds through studies of weed biology and ecology, and establishing the platform for training, education, and extension through a coordinated approach, were at play, as reviewed below.

Ecological Perspectives to Understand *What Weeds Are*

Looking back at the history of Biological Science and Weed Science, we see the '*period of ecological enlightenment*' somewhere between 1960 and 1975, when Herbert Baker initially formulated thoughts on what might be '*an ideal weed*' (Baker, 1965). Contributions from other giants in Ecology, Charles Elton (Elton, 1959), Jack Harlan (Harlan, 1965), Ledyard Stebbins (Stebbins, 1965), John Harper (Harper, 1957b; 1960; 1965) and Hugh Bunting (Bunting, 1960), to name a few, also led to our current understanding of *what weeds really are*. Ideas and views espoused by these pioneers shaped and moulded weed research, setting in motion directions for Weed Science to evolve, and indeed the careers of a large number of weed scientists.

The potential of 'globe-trotting', invasive species, both plants and animals, had already been mooted in 1958 by Charles Elton in his landmark thesis (Elton, 1958). Evidence of many weeds in cultivated fields being 'wild relatives of crops' had been also compellingly compiled and presented (see Harlan and De Wet, 1965). Not to miss the point, Jack Harlan also pointed out the remarkable similarities between the greatest weed of them all - humans - and other '*colonizing species*'(see discussion in Chandrasena, 2015).

It would be fair to say that the scientific enquiries and ecological perspectives referred to above, continue to be seminal ideas in our attempts to explain *what weeds are* and *why they behave in the way they do*. This understanding should underpin everything weed scientists do, although, we lament that *understanding lags a long way behind practice* when it comes to weeds. '*Know Your Enemy*' is a catch cry we do not subscribe to, because we do not consider weeds as enemies. Many weeds have redeeming values, and are useful biological resources to various cultures and societies. However, war metaphors have been, and are still often used in slogans associated with weed control. Instead of understanding the true nature of the organisms we are dealing with, we find critical aspects of their ecology and biology are often overlooked by a good proportion of both weed researchers and weed control practitioners, leading to poorly executed research and weed control.

By late 1950s and early-1960s, as university departments and faculties expanded all over the world, the gap between 'basic science' (covering topics like Plant taxonomy, genetics, physiology, biochemistry, evolution, and ecology) and 'applied science' (such as agronomy, soil science and crop protection) opened up widely in academia. This created a strong disconnection between the understanding of the biology and ecology of weeds, leading to poorly executed weed control research and interpretation of results.

For several decades in the past 50 years, we find weed control research reported essentially as part of cropping, without much thought on why and how, and a tendency to shunt ecology and biology away as unimportant. A large amount of weed research, reported at APWSS Conferences and other forums, therefore, suffer from inadequate demonstration of an understanding of basic Botany and Plant Ecology, subjects that underpin the 'science' of weeds. Many scientists think that a basic understanding of 'Science' is necessary before a practical application is developed; therefore, 'Applied Science' relies on the results generated through basic science. Others favour a move away from basic science to find solutions to actual problems. Both approaches are valid in our view. Whilst it is true that some weed problems demand immediate attention, few effective and sustainable, weed control solutions would be found without the help of the knowledge foundation generated through basic Weed Science. Perhaps, our APWSS founders were also concerned 50 years ago of the inadequacy of application of scientific methods in the region?

Impacts of Excessive Dependence on Pesticides and Herbicides

During the 1950s and 1960s, rumblings of trouble were beginning to be heard (see Duke, 2005). The discipline of Weed Science came under criticism by some as being nothing more than 'herbicide science' and a conduit for herbicide companies to market their products, which were in an expansion mode. Although the focus quickly changed to capture studies in weed biology and ecology, as well as non-herbicidal weed control methods, the perception that Weed Science was a discipline, largely focused on herbicides, continued for many years, perhaps with some negative consequences. Introducing an influential symposium, organized by the *British Ecological Society*, held at Oxford, U.K., during 2-4 April 1959, John Harper (1960) wrote:

> *"…this Symposium has been concerned with the biology of weeds, which has been interpreted to exclude chemical control. This has been a deliberate policy, because symposia and conferences in weed control have been held in abundance. Herbicides are, however, so widespread in use that they are beginning to form part of the 'normal' environment of weed populations. Already weed strains have been selected, which are resistant to some of the chemical herbicides. It will be a tragedy if the botanist does not take opportunities now offered to follow the influences of this most potent force on the distribution, frequency, evolution, and dynamics of weed populations…"* (Harper, 1960)

This 1959 meeting highlighted the need to focus on the taxonomy, biology and ecology, including reproduction systems, and the evolution of weeds. It impressed the scientific community to commence studies of weeds from an individual perspective (autecology), and as part of populations and communities (synecology).

Keeping herbicides out of the Symposium, John Harper steered the directions Weed research should take, which were pivotal in the development of our discipline. Three years earlier, he had already prophetically sounded the early warnings on the dangers of overuse of herbicides and the likely development of herbicide resistance in weeds (Harper, 1956; 1957b).

Looking back at history, a much more influential symposium – the *First International Union of Biological Sciences Symposia on General Biology* – was subsequently held in California, during 12-16 February 1964. The proceedings – *Genetics of Colonizing Species* - Edited by Baker and Stebbins (1965) are regarded by many ecologists as a seminal landmark in the evolution of Weed Science, because several evolutionary biologists made remarkable contributions at the Conference to the field of biological science, offering a glimpse of how Darwin's theory of evolution might actually be operating in Nature. As the Editors stated:

> *"…the Symposium had as its object, the bringing together of geneticists, ecologists, taxonomists and scientists working in some of the more applied phases of ecology –such as wildlife conservation, weed control, and biological control of insect pests..."* Baker and Stebbins (1965)

The explanation of possible genetic systems operating within 'colonizing species' brought the discourse of weeds to a higher plateau than before. With a focus squarely on *Plant Science*, it stimulated research over the next few decades on using weeds as model, experimental organisms to understand how plant populations behave. This, combined with studies on the biology, ecology and eco-physiology of individual weed species changed the direction of Weed Science forever, which, up to that time, had an inordinately unbalanced focus on herbicides. Concurrently, during this period of *ecological enlightenment*, the heightened awareness obtained on plant and animal population biology and ecological perspectives on weeds (i.e. related to succession, vacant niches, see Baker, 1965), brought in more 'science' to the Weed Science discipline.

By the early 1960s, other societies of biologists and ecologists influenced the directions of weed research across the globe. This brought about a change of focus of Weed Science on to studies of weeds, as biological organisms, and not just the examination of herbicides, to kill them. Stimulating the discourse on converting ecological theory into practical management of plant and animal populations, the *British Ecological Society* launched the *Journal of Applied Ecology*, in the heady days of the early 1960s.

Launching the Journal, its first editors Hugh Bunting and Vero Copner Wynne-Edwards optimistically wrote (Ormerod and Watkinson, 2000):

> *"…Ours is an age in which ecological thinking and methods can, more than ever before, contribute to the progress of mankind…' (1964), Journal of Applied Ecology, 1, pp. 1-2.*

Reviewing the literature, we find that the turnaround of focus to *understand weeds*, as purely a group of plants with special attributes for colonizing vacant niches created by disturbances, was achieved at least about 10 years prior to the formation of APWSS. Perhaps the amplified awareness on the need to *understand weeds, as a basis for their control* may have influenced the thinking of our founders at that time. It is also probable that they were concerned about the potential for any technology, particularly, herbicide technology, to go wrong when it is used without an appreciation of unintended consequences and collateral damage.

Apart from the *Genetics of Colonizing Spe*cies, we may also add Rachel Carson's major contribution, *Silent Spring*, published in 1962 (Carson, 1962) as a landmark, which influenced the development of Weed Science. The book sounded an ominous warning to the scientific community on the adverse impacts of excessive pesticide use across USA, including the large-scale use of herbicides. *Silent Spring* was inaccurately criticized within the Weed Science community (Robert Zimdahl, *pers. comm*., July 2017). However, the impact of *Silent Spring* was a vastly increased regulatory control of all pesticides, and the mandatory requirement for comprehensive research data on modes of action, efficacy, toxicology, and environmental fate of xenobiotics.

The stringent approval requirements increased research efforts on all pesticide applications. The additional costs for herbicide/pesticide evaluations slowed down new discoveries considerably. The mandatory requirements for registration resulted in increased funding, which promoted closer working relationships between researchers, the pesticide/herbicide industry, independent reviews, and efficacy evaluations. Both these influences, it could be argued, would have had positive and negative consequences.

The mandatory studies in the environmental fate and toxicology of pesticides, particularly on aquatic and soil biota, strongly increased the environmental awareness of the potential and real effects of overuse of chemicals, and public perceptions of those risks. Closer working relationships between researchers and the industry, some would argue, effectively stifled dissent, and objective assessment of such impacts, so that the required improvements with regard to responsible use of chemicals could be made.

Due to the strong marketing campaigns by herbicide manufacturers in the 1970s through to 1990s, in the early days, *Weed Science might have been properly called Herbicide Science* (Thill *et al.*, 1991). Lamenting on this negative perception, Donald Wyse stated twenty-five years ago (1992):

> *"…A large portion of resources devoted to Weed Science have been devoted to herbicide research and promotion of their use. The over-emphasis on chemical weed control by many weed scientists will continue to retard the development of Weed Science as a balanced discipline…"* (Wyse, 1992).

With the recognition of the need to anchor Weed Science in its basic sciences – *Botany* and *Ecology*, over the next two decades, the emphasis shifted from herbicides to a more holistic, integrated weed management (IWM) approach (Thill *et al.*, 1991; Wyse, 1992; Zimdahl, 2012). Public concerns on the potential impacts of widespread pesticide use had driven the science of managing insect pests towards integrated pest management (IPM) at that time. Following in the same direction, IWM was an effort to, in Zimdahl's words (2012): *"…overcome the paralysis of the pesticide paradigm and conceive a Weed Science research program that addresses both society's perceptions of safety and the scientific community's perceptions of risks…"*

The discourses at that time responded to public pressure, and included scientific ideas on population and community ecology, the genetic basis of evolution, carrying capacity of ecosystems, limiting resources and limits of growth. Arguments for reducing the large loads of herbicide and other pesticides used in agriculture swirled around in the 1960s and 1970s. A primary motivation was to achieve acceptable levels of environmental safety, while mitigating the negative economic impacts of weeds and pests with chemicals.

Whilst herbicide-based research continued on aspects, such as reducing herbicide contamination of surface and ground water resources, and modifying application technology to increase weed control efficiency, IWM stimulated research and practical applications, incorporating all of the available weed control methods, based on ecological principles, weed thresholds, as well as economic goals of weed control.

IWM also shifted the emphasis from 'weed control' to 'weed management', with the incorporation of knowledge of population biology (e.g., weed seed population dynamics; soil seed bank; species shifts over time) into control programmes. Other vital elements in IWM included weed hygiene (preventative weed control); cultural practices (i.e. crop rotations, multiple cropping, minimum tillage, crop residue uses, and manipulations of water and nutrients) and biological control. The primary intentions were sustainable weed management, and large-scale reductions in herbicides used for weed control, in the advanced economies, at that time.

Other Historical Events

Strong linkages began forming in the 1950s among herbicide industry scientists, weed researchers in Universities, professional weed managers and extension staff in the public sector, across the developed regions in North America and Europe. The early networks also included farming lobby groups, and environmentalists. With regard to historical perspectives on the formation of Weed Science Societies and landmark events, which preceded the formation of the APWSS, we highlight the following:

- As public interest grew, among farmers, scientists and industry, the first dedicated weed journal in the USA (called, *Weeds*) was launched in 1951 as the journal of the Association of Regional Weed Control Conferences. This was followed by the formation of the Weed Science Society of America (WSSA) in 1956, which took over the publication of *Weeds*; and re-named it *Weed Science* in 1968.

- The European Weed research Council (EWRC), which later became the European Weed research Society (EWRS)[21] was formed in 1958, and launched its official journal Weed research in 1961.

- As previously indicated, the British Ecological Society launched its influential journal - the Journal of Applied Ecology in 1964 - to *promote the application of ecological theory to improve policy and management decisions on biodiversity, ecosystems, natural systems, environment and natural landscapes*.

- In Australia, the First *Australian Weed Conference* was held in 1954, under the auspices of the Australian Agricultural Council, although the first Weed Science Society in Australia - the *Weed Society of New South Wales*, was formed in 1966, a year before APWSS was formed.

- The Hyacinth Control Society was formed in 1961 primarily for weed managers to share information on their efforts to control water hyacinth [*Eichhornia crassipes* (Mart.) Solms] in Florida's lakes, rivers and canals (Schardt, 2010). The *Hyacinth Control Journal* began in August 1962, to provide information about water hyacinth control to aquatic plant managers. The Society then broadened its scope in the 1970s to address plant management issues across the USA, re-incorporating as *The Aquatic Plant Management Society* (APMS). The Hyacinth Control Journal was expanded and re-named the *Journal of Aquatic Plant Management* to address all invasive aquatic plants.

[21] In May 1958, a meeting of Weed scientists in Ghent (Belgium) set up an international working group to accelerate progress in solving weed problems. The first outcome was to a conference at Stuttgart-Hohenheim where Project Groups on bracken, wild oats, and methods of herbicide evaluation were organized. The EWRC was established at a second meeting at Oxford in 1960. The Council became a fully-fledged Society in 1975 with 24 member country representatives. The 1960 meeting also started the journal Weed Research.

- In 1966, the US Agency for International Development (USAID) launched a major effort to develop weed control in the USAID aided nations. The program was carried out through a contract with the International Plant Protection Center (IPPC) of the Oregon State University (see Furtick, 1969).
- The British Crop Protection Council (BCPC)[22] was established in 1968. Renowned for the '*Brighton Weed Conference*', BCPC celebrates its 50th Anniversary in 2017. Its 'Weeds Working Group' was established initially in 1968, almost coinciding with the founding of the APWSS.
- The *Canada Weed Committee* – the precursor to *The Canadian Weed Science Society* – with 15 government-appointed members, was formed in 1968[23].
- The *Indian Society for Weed Science* (ISWS) was established in 1968. Publishing of its journal 'Indian Journal of Weed Science' began in 1969.

In spite of the universal importance of weeds as a limiting factor in food production and the vast amount of herbicides being used for vegetation control in various situations, throughout the 1950s and 1960s, government support for Weed Science and weed research in almost all countries was lukewarm. A viewpoint that prevailed at that time was that weed research should be largely left to the agrochemical industry, which had proven to be outstandingly successful in developing and marketing herbicides, across the globe, making huge profits. Perhaps, an important difference was lost in that discourse: marketing of herbicides and/or other pesticides and deep scientific enquiry in to weeds and their control are quite different activities.

A second viewpoint was that fundamental aspects of weed research should be left to the university sector, which, in theory, was well set up to undertake the required research. In practice, however, the agrochemical industry, like any other industry, faced ever-increasing commercial pressures, which limited what they could achieve in terms of herbicide development, leaving many gaps to be filled. In addition, university research was restricted by individual interests and expertise of incumbent staff, finance, the need to select projects suitable for completion of post-graduate student thesis within 3-4 years. Whilst universities were acknowledged as the doyens of conceptualization, scientific theory, and sometimes, applied research, they were handicapped by weak linkages with industry and real-life on-farm agriculture. They were also unable to operate as commercial enterprises, doing 'science' and commercialization of findings simultaneously, in the industrial context, perhaps until recent decades[24] Essentially, this left the more practical side of weed control and testing of herbicides in the hands of enthusiastic, but often, inadequately-resourced agronomists, and ill-equipped organizations, who had little hope of solving major weed problems with in depth understanding of weeds.

It is interesting to note an overt criticism in Furtick's words, made in 1969: "…*professional agriculturists in the region are oblivious of the basic importance of weed control*…" He was referring to the apparent deficiencies in weed control across the major crops in the Asian-Pacific region, which had not quite caught up with the 'winds of change' blowing across North America and Europe, in particular.

[22] The BCPC was founded in 1968 when the British Weed Control Council (set up in 1953) and the British Insecticide & Fungicide Council (set up in 1962) merged to form a single body.

[23] The Canada Weed Committee was renamed in 1978 as the '*Expert Committee on Weeds*', a name that endured the ensuing 25 years. The Canadian Weed Science Society was finally formed in 2002 by amalgamating various precursor groups (such as the Wild Oat Action Committee and Quack grass Action Committee).

Given this, we believe that APWSS was conceived because of the need for 'collective bodies' to help plan and take action, and co-ordinate the implementation of weed control programs through interactions, and collaborations among 'like-minded' people in the Asian-Pacific region.

APWSS – From Weed Control to Weed Science

The Founding Years (1967-79)

Our review of the founding event and the first ten years of APWSS activities indicates a great deal of passion, enthusiasm, and unmitigated goodwill to collaborate on Weed research and to find practical solutions for weed problems that plagued many of the developing countries of the region. 'Food security' for developing nations was a central theme in the deliberations. Excerpts of a released communiqué, from the East-West Center, announcing the formation of the APWSS, reveals it (APWSS, 1967):

> *"…Representatives of 21 Countries meeting in Hawaii have formed an International Body to attack the mounting food shortage in tropical areas through weed control. The organization is the Asian-Pacific Weed Science Society; and it was organized by a recent weed control conference sponsored jointly by the University of Hawaii's College of Tropical Agriculture and the East-West Center's Institute for Technical Interchange.*
>
> *The Society will seek to stimulate research into how extensively weeds limit food production in the tropics, giving major attention to rice in Asia and to coconuts in the Pacific. Also, the Society will promote the design and application of weed control programs, including training programs, best suited to the agriculture, economics, cultures, and traditions of emerging countries…*
>
> *To date, most research in weed control and the use of herbicides and equipment has been confirmed to the temperate zone. The recent weed control conference brought out that there are 3000 to 5000 trained workers in the temperate zone, compared with fewer than 100 in the tropics. So scanty has been research in the tropics that it is not even known how much food production is lost to weeds, and, conversely, how greatly production might be expanded through proper controls. But, although firm data are lacking, it is surmised that weeds stifle as much as 40% of production in the tropics…"*

Table 1 presents summary details of papers presented at the APWSS Conferences in the early years. Topics discussed at the founding conference clearly reveal the intents. They include new herbicides, and herbicides for weed control in rice and other agronomic crops, pastures, horticultural crops and brushlands. Some attention was paid to herbicide physiology and degradation, while general topics included the importance of conducting weeds surveys in different countries and the role of education, training, and extension.

None of the papers at the founding Conference could be classed as studies in Weed Biology or Ecology. However, reflecting the mood at that time, the case for herbicide use to better control weeds and achieve increased crop yields was strongly argued. The founding Conference also strongly advocated for weed surveys in individual countries to address the dearth of weed information. It also highlighted the importance of training of weed workers, and 'taking the message to the farmers' through extension.

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[24] An example of a high-impact, academic product, related to Weed Science, that has been commercialized on a global scale is genetically modified organisms (GMOs).

Table 1: Major categories of papers and presentations at APWSS Conferences, 1967-79*

Topic	1967	1969	1971	1973	1975	1977	1979
New Herbicides	5	3	3	5	13	8	8
Rice Weed Control, including herbicides	11	12	17	6	12	3	9
Weed Control in agronomic crops, including herbicides	9	8	14	17	14	18	36
Weed Control in horticulture, forestry, plantation crops, including herbicides	6	3	3	10	15	16	24
Herbicide mode of action, soil residues, metabolism, physiology, biochemistry	6	6	3	12	21	11	8
Non-herbicide methods, including biological/cultural control	0	0	1	0	4	5	13
Weed biology, ecology	0	5	5	16	13	23	24
General, perspectives, weed surveys	10	6	5	4	6	3	6
Legislation, education, training, extension	5	2	1	8	0	4	6
Total	**52**	**45**	**52**	**78**	**98**	**91**	**134**
Total related to Herbicides	71%	71%	77%	64%	77%	62%	63%

* We followed a general sense, obvious in the paper titles and sometimes, indicated by the themes in the published Proceedings to attribute the APWSS Conference papers to different themes, in this Table and those to follow. There may be some errors in attribution, although these are likely to be minor.

In those early years, herbicide-related presentations dominated the Conferences - up about 60-70% of the papers presented (Table 1). The herbicide research would have excited the region's weed scientists. It initially revolved around introducing new herbicides, demonstrating their efficacy in controlling weeds in a variety of crops, cost-benefits, and potential economic gains. In later years, herbicide efficacy trials were complemented by studies of modes of action, selectivity and the environmental fate of those chemicals.

As Zimdahl (2012) pointed out, many Weed Science textbooks and journal papers published in the 1960s, 1970s and 1980s devoted more than 50% of their contents to characterizing herbicides, herbicide modes of action and herbicide-environment interactions, showing a *collective commitment to herbicides as the best solution to weed problems*. As evident in the data (Table 1), APWSS proceedings were not much different those days. The founding years also set the pattern for the next decade (see APWSS, 1988), introducing the previously mentioned themes under which papers were presented. Enthusiasm to educate and train people in not just in weed control, but also in scientific enquiry, was also evident in the early inter-changes.

In the early days, not much attention was paid to aspects, such as surveys to identify major weed problems; new species and their taxonomy; ecology and biology of major species; and various non-herbicide based methods that might be effectively deployed against weeds. Weed impacts in the environment hardly got a mention in the early days, except for perhaps, aquatic weeds. At the second Conference, in 1969, Le Roy Holm and James Herberger described the task of compiling an inventory of "*The World's Worst Weeds*" with a global focus. Up to that time, there was no compendium of weeds, which had the greatest impact on agriculture and other human endeavours. Holm and Herberger (1969) expressed concern for the dearth of real data and information on priority weeds, as well as trained personnel in the Asian-Pacific region at that time:

> *"…there are about 200,000 species of angiosperms recorded. Some estimates suggest that 30, 000 of these may behave as weeds. We have looked at about 3000; and were very soon able to reduce the list of weed species to 100. It appears now that about 50 of these maybe worth serious consideration on a world basis. On a world basis, surely, one of the characteristics of a troublesome species is that it has established itself over all or most of the agricultural regions of the earth. Cyperus rotundus* L.*, a native of Asia, may be the world's worst weed. It is in all of the major crops and most of the important agricultural regions of the world…*
>
> *We are short of weed workers for most countries. The world always seems short of funds for weed research. Yet, the use of herbicides is increasing very rapidly and we need good and wise men to guide and counsel us during this rapid change in the use of a pesticide. We need more training centers. The biology and life histories of most of our serious weeds have never been studied. With so much to do, and with meagre resources, we need to act wisely and not run off in the wrong direction with our time and effort. We need to know what the World's Worst Weeds' are, so that we can do first things first…"* (Holm and Herberger, 1969)

Table 2 provides the list of species Holm and Herberger named '*The World's Worst Weeds*'. The information on the distribution, biology, habitat, agricultural importance and other aspects of these weeds, compiled in the treatise (Holm *et al*., 1977; 1979), and the rankings provided, with the basis explained, were pivotal in drawing the attention of the Weed Science community to the importance of addressing specific species, as a matter of priority. These efforts, led by Le Roy Holm, jointly with other senior weed researchers, are considered by many as landmarks in the global Weed Science corpus of knowledge.

We believe that 'taking stock' of which weeds should be focused on and how, whilst tolerating those minor species that really had no impact on crop yields, changed the way weed scientists thought about weeds. A new focus on weed biology and ecology occurred, evident from the marked increase in such papers at the fourth APWSS Conference. This increased focus was also influenced by the host country – New Zealand. As an 'island' nation, with borders protected by the oceans, New Zealand, by this time, had begun to query the correlation between human-mediated introduction of essentially, European weeds to the country, and spread of those species due to land-use practices, such as pasture establishment and forestry.

The early Conferences focused heavily on rice, the most important crop in the Asian-Pacific region, with barnyard grass (*Echinochloa* spp.), sedges (mostly, *Cyperus* spp.) and broad-leaf, rice weeds receiving the most attention. Following the adoption of high-yielding varieties (HYVs), herbicide-based control strategies for weeds affecting all other major cereals (wheat, maize, and sorghum) also received attention, followed by upland crops (pulses, vegetables, sugar cane, pineapple, etc.) and plantation crops. The papers reveal considerable concerns about lack of information on impacts of weeds on those crops.

Table 2: The World's Worst Weeds Top 18 as Listed by Holm and Herberger (1969)*

Family	Botanical Name	Common Name	Ranking
Cyperaceae	*Cyperus rotundus* L.	Purple Nutsedge	1
Poaceae	*Cynodon dactylon* (L.) Pers.	Bermuda grass; Couch grass	2
Poaceae	*Echinochloa crus-galli* (L.) Beauv.	Barnyard grass	3
Poaceae	*Echinochloa colonum* (L.) Link	Jungle Rice	4
Poaceae	*Eleusine indica* (L.) Gaertn.	Goose grass	5
Poaceae	*Sorghum halepense* (L.) Pers.	Johnson grass; Aleppo grass	6
Poaceae	*Imperata cylindrical* (L.) Beauv.	Cogon grass; Alang-alang	7
Pontederiaceae	*Eichhornia crassipes* (Mart.) Solms	Water Hyacinth	8
Portulacaceae	*Portulaca oleracea* L.	Purslane	9
Chenopodiaceae	*Chenopodium album* L.	Fat Hen; Lambs Quarters	10
Poaceae	*Digitalia sanguinalis* (L.) Scop.	Large Crabgrass	11
Convolvulaceae	*Convolvulus arvensis* L.	Field Bindweed	12
Poaceae	*Avena fatua* L.	Wild Oats	13
Amaranthaceae	*Amaranthus hybridus* L.	Slim Amaranth; Smooth Amaranth	14
Amaranthaceae	*Amaranthus spinosus* L.	Prickly Amaranth; Spiny Amaranth	15
Cyperaceae	*Cyperus esculentus* L.	Yellow Nutsedge; Nutgrass	16
Poaceae	*Paspalum conjugatum* Berg.	Paspalum; Sour grass	17
Poaceae	*Rottboellia exaltata* L. f.	Kokoma grass; Guineafowl grass	18

*Listed in Group 1, are the 18 most serious weeds, in the approximate order in which the species are reported as 'troublesome' by the World's agriculturists. The top 10 in the above list stand apart from all other weed species as they are the most often cited troublemakers in the largest number of field crops in the largest number of countries.

For rice, the selective herbicides – MCPA and 2, 4-D (for broad-leaf weed control) and propanil (for the control of barnyard grass and sedges) - had already been in use for about 20 years in USA. However, adoption had been slow in the Asian-Pacific region. There was inadequate information on cost-benefit advantages, even though the early deliberations advocated the use of these herbicides more widely. The herbicide industry also used APWSS Conferences to introduce major rice herbicides, such as butachlor, thiobencarb, nitrofen, oxyfluorfen, and bifenox in the region. Efficacy demonstrations stimulated wide-scale adoption.

Ending the first decade, at the 5th Conference, held in Japan, there was a heavy focus on the integrated management of rice and other weeds with a special symposium. Overall, the first decade of APWSS Conferences and deliberations ended with a great deal of optimism, and recommendations for the adoption of herbicides as a primary tool for improving weed control in the region. Whilst the focus was squarely on the use of herbicides, the decade also embraced the importance of ecological studies on weeds; integrated weed management, as well as the need for the collection of economic data on yield losses of rice and other crops that can be attributed to weeds.

The Middle Years (1981-1989) - Changing Weed Research Needs

There is no doubt that herbicides began to be adopted readily for weed control during the 1970s, with Japan, Korea, and Taiwan (ROC) leading the way. This trend continued in the 1980s, transforming the way weeds in the Asian-Pacific region were managed in major crops, particularly rice. New discoveries excited Weed researchers; and aggressive marketing by industry led to adoption of various herbicides and their combinations, as well as split-applications and sequential treatments into weed control programs.

The literature reveals a large number of papers in the 1980s (see Table 3), dedicated to practical applications of existing herbicides (2, 4-D, paraquat, asulam, atrazine, glyphosate, etc.) in various agricultural settings, including 'minimum tillage' cultivation. The promotion of numerous combinations of established rice herbicides (such as propanil, molinate, butachlor, oxyfluorfen, thiobencarb, etc.), integrated with improved cultivars, water level management, nutrient management, and cultural weed control, contributed to marked increases in rice yields across the region.

Of particular importance during this period was the development of glyphosate for non-selective, broad-spectrum weed control in 'minimum tillage', and its application using 'wiping' techniques. Reflecting these shifts, herbicide-related discussions accounted for an average of 60% of papers presented.

Table 3: Major categories of papers and presentations at APWSS Conferences, 1981-1989

Topic	1981	1983	1985	1987	1989
New Herbicides	8	13	13	25	20
Rice Weed Control, including herbicides	5	16	4	5	18
Weed Control in agronomic crops, including herbicides	26	4	16	23	9
Weed Control in horticulture, forestry, plantation crops, including herbicides	30	6	4	30	5
Herbicide mode of action, soil residues, metabolism, physiology, biochemistry	6	6	22	19	14
Non-herbicide control, including biological and cultural control	14	8	8	8	12
Weed biology, ecology	18	17	33	26	29
General, perspectives, weed surveys	9	7	7	5	12
Legislation, education, training, extension	4	3	3	3	2
Total	**120**	**80**	**110**	**144**	**121**
Total related to Herbicides	63%	56%	54%	71%	55%

In addition to the expanded use of existing herbicides, the 1980s also saw the introduction of new classes of herbicides, in particular, sulfonylureas (bensulfuron, metsulfuron, and others)and 'graminicides', including fluazifop-butyl and haloxyfop-methyl to the region. Effective at much lower rates than the older herbicides, sulfonylureas gave the opportunity to reduce herbicide loads in the environment. The highly selective activity of the graminicides enhanced the prospects of controlling troublesome, tropical grasses in the region, such as cogon grass (*Imperata cylindrica*) and torpedograss (*Panicum repens* L.).

Some highlights and landmarks of these 'Middle Years' APWSS Conferences are presented below:

- A literature review will detect influence of host countries on the APWSS deliberations. For instance, the 8th Conference in 1981 (India), attracted a large number of papers on weeds in upland crops, biological control, weed ecology and allelopathy. The 8th Conference introduced fluazifop-butyl (Fusilade®) for grass weed control; and a new rice herbicide - anilofos (HOE 30374™) to the region.
- Common weeds in upland crops were highlighted at this Conference, which also focused on emerging problems in the South-Asian region. The first paper on parthenium weed (*Parthenium hysterophorus* L.) emerging as a major problem in the region was at the 1981 Conference.
- At the 9th Conference, in 1983, hosted by the Philippines, a similar trend continued with a heightened emphasis on eco-physiological aspects of major weeds of the region and their integrated management. Discussions on novel biological control agents and allelopathy broadened the scope of weed research.
- Whilst championing the benefits of fluazifop-butyl, haloxyfop, and fenoxaprop-ethyl for grass weed control, the Manila Conference introduced Pretilachlor (Sofit®), mefenacet® and the pyrazole herbicide - benzofenap (NC-310™; Taipan®) as highly effective, pre-emergence, broad-spectrum herbicides for transplanted or direct-seeded rice. For broad-spectrum weed control in upland crops, the non-selective herbicide - glufosinate ammonium (Basta®) and the imidazoline herbicide - imazypyr (Arsenal®) were also first introduced at this 9th APWSS Conference.
- At the 10th Conference (Thailand), the effectiveness of bio-control insects- weevils: *Cyrtobagus salvinniae* Caulder & Sands, against salvinia (*Salvinia molesta* D. S. Mitchell) and *Neochetina eichhorniae* Warner, against water hyacinth - was demonstrated. The problem of giant mimosa (*Mimosa pigra* L.) in the region, including Northern Australia, was also first highlighted in 1985.
- Both the 11th Conference (1987) at Taipei, Taiwan (ROC) and the 12th Conference (1989) at Seoul, Korea were dominated by rice, reflecting major transformations occurring at that time in Asian rice cultivation. As Japan, Korea, and Taiwan headed towards achieving self-sufficiency in rice production, the research demonstrated heavy dependence on herbicides for achieving higher yields.
- A new herbicide class - sulfonylureas (bensulfuron; metsulfuron, pyrazosulfuron and cinosulfuron) was introduced for both transplanted and direct-seeded rice, with biological activity in the range of 10-40 g a.i. ha^{-1} transforming weed management in rice. Other rice herbicides introduced included dithiopyr (Mon 7200™) and cinmethylin®. Imazethapyr (Pursuit®) with broad-spectrum activity on grasses and other weeds were also introduced at the 1989 Conference in Korea.
- Both the 1987 and 1989 Conferences strongly advocated integrating allelopathy into weed management with comprehensive reviews of information available. Nevertheless, the introduction of so many new herbicides to the region, and discussions of other herbicides (such as fluroxypyr and imazapyr) indicates that the 1980s was really the 'herbicide decade' in the Asian-Pacific region.

The Maturing Years, 1991-1999

Increased herbicide use thus became an indispensable part of agriculture in most countries of the region in the 1990s. An average of 54% of papers presented at APWSS Conferences during this decade covered this aspect. However, concerns on the environmental safety, and the emergence of herbicide resistant weeds, attributed to overuse of chemicals, began to be voiced at the APWSS Conferences. The word 'sustainable agriculture' and 'sustainable weed management' appeared several times in the Conferences' main themes, during this period, indicating the concerns of the community.

Table 4: Major categories of papers and presentations at APWSS Conferences, 1991-1999

Topic	1991	1993	1995	1997	1999
New Herbicides	3	13	13	8	16
Rice Weed Control, including herbicides	4	6	12	8	15
Weed Control in agronomic crops, including herbicides	7	18	23	8	30
Weed Control in horticulture, forestry, plantation crops, including herbicides	5	3	13	12	12
Herbicide mode of action, soil residues, metabolism, physiology, biochemistry	3	11	43	15	20
Herbicide Resistance – mechanisms and management	0	3	3	9	2
Non-herbicide control, including biological/cultural control	3	17	16	6	13
Weed biology, ecology	10	24	25	25	46
General, perspectives, weed surveys	3	15	17	5	7
Legislation, education, training, extension	2	5	6	3	0
Total	40	115	171	99	161
Total related to Herbicides	55%	44%	63%	52%	58%

The following is a brief summary of highlights in this decade:

- Additional, new chemicals were introduced, with prospects for more effective broad-spectrum weed control in rice. Apart from sulfonylureas, the research demonstrated how quinclorac, pretilachlor and other herbicides could be integrated with cultural control and water level management.
- New rice herbicides included the following: cyclosulfamuron (introduced in 1993 at the 14th Conference), pyribenzoxim, tralkoxydim (EK 2612) in 1997. The 'One Shot' herbicide (Riceguard®), which combined anilofos and ethoxysulfuron, was first introduced in 1997 for both transplanted and DSR. Bispyribac-sodium (Nominee®) from Kumiai Chemicals Japan, was also released for use as a post-emergence herbicide in DSR, and for broader weed control on rice levees and rights-of-way in 1997.
- At the 15th Conference (1995), at least three new herbicides for upland crops were introduced: cyhalofop-butyl (Clincher®); sulfosulfuron, to control grasses and broadleaf weeds in wheat; and halosulfuron for the control of purple nutsedge in upland crops. At the 16th Conference (1997), under new herbicides, pyraflufen-ethyl and imazapic were introduced for broadleaf weed control in wheat and other crops.
- The 1990s also saw a large volume of research on environmental impacts and mobility of herbicides in soil and water. The Conferences devoted significant time discussing how to optimize herbicide delivery, to mitigate the non-target effects, while questioning the over-reliance on herbicides. During this period, various weed problems in the region were highlighted, including the first occurrence of 'weedy rice' in Japan, which had originated from inter-breeding of wilder strains with modern cultivars (Watanabe, 1995). Similar 'weedy rice' problems in Malaysia and Korea were also highlighted.

- Weed ecology and biology, allelopathy, biological control and other tools for weed management were well covered. Under non-herbicide control, various countries reported on the successes of releasing the water hyacinth weevils - *Neochetina eichhorniae*, and *Neochetina bruchi* Hustache in the region, along with the moth - *Sameodes albugattalis* Warren. Research also focussed on the possibility of developing fungal pathogens as bio-control agents (mycoherbicides) for major weeds, including barnyard grass.

- Herbicide resistance became a new theme for discussion within the Asian-Pacific region in the early 1980s. An early example was canary grass (*Phalarisminor* Retz.), a major weed in wheat, in the north-western regions of India, which had become resistant to isopropturon, due to continuous use of this single herbicide, for 10-15 years. The research led in the withdrawal of isopropturon and substitution by four alternate herbicides (clodinafop, fenoxaprop, sulfosulfuron, and tralkoxydim) to manage canary grass resistance in India (Kirkwood *et al*., 1997). From Australia, Taylor (1996) reported on the development of resistance to bensulfuron in barnyard grass and other major rice weeds. This herbicide had been used in 90% of Australian rice fields for at least 10 consecutive years, since 1985. Resistance management involved combining sequential applications of alternate mode of action herbicides (molinate, thiobencarb, bensulfuron, and MCPA) at lower rates than label recommendations, combined with cultural control.

- Other presentations in the decade highlighted a much more concerning development, that of cross-resistance to herbicides. For example, Tiw *et al*. (1997) described the development of simultaneous resistance in goose grass [*Eleusine indica* (L.) Gaertn.] to herbicides from both classes 'fops' (aryloxyphenoxy-propionates) and 'dims' (cyclohexanediones). Although they are quite different classes of herbicides, their mode of action is common, i.e. both inhibit the enzyme ACCase (acetyl co-enzyme A carboxylase), which catalyzes the first step in fatty acid synthesis in plants.

The New Millennium Years, 2001-2015

The new millennium years ushered in a reduced focus on herbicides and less time devoted to chemicals (see Table 5). Persistent reports on negative environmental impacts, concerns about human safety, and the ever-increasing number of herbicide resistant weeds (see Heap, 2015) appeared to shift emphasis from herbicides to more sustainable, integrated approaches.

The re-invigoration of preventative control (i.e. weed hygiene, border protection), with an emphasis on weed seed banks, vehicles of weed spread and 'invasion pathways', was a new era that moved the discipline from weed control to weed management, and also from reactive, tactical weed control to a more pre-emptive and strategic frame of mind.

An increase in the number of papers presented on such topics attest to the fact that the APWSS community, in the New Millennium, had begun to appreciate the benefits of approaching weed problems more holistically and connecting with broader issues of land, water, and environmental management, as well as climate change. Conference themes of '*Ecologically-based Weed Management for Sustainable Agriculture*' in 2001; '*Sustainable Development*' in 2003, 2005, and 2015; '*Food Security*' in 2013 demonstrate somewhat of an 'awakening' within the APWSS community and a re-focussing of attention to those aspects.

Table 5: Major categories of papers and presentations at APWSS Conferences, 2001-2015

Topic	2001	2003	2005	2007	2010*	2011	2013	2015
New Herbicides	12	8	6	5	0	3	0	5
Rice Weed Control, including herbicides	14	12	32	8	10	3	7	15
Weed Control in agronomic crops, including herbicides	9	5	18	5	9	6	13	14
Weed Control in horticulture, forestry, plantation crops, including herbicides	8	2	16	12	7	11	7	23
Herbicide mode of action, soil residues, metabolism, physiology, biochemistry	8	5	6	25	2	12	6	11
Herbicide Resistance – mechanisms, management	13	14	3	2	2	10	10	13
Non-herbicide control, including biological/ cultural control and allelopathy	15	28	8	29	22	11	29	26
Weed biology, ecology	52	29	9	38	45	41	17	32
General, perspectives, weed surveys	8	10	10	6	7	11	8	
Legislation, education, training, extension	3	5	3	2	1	2	5	
Total	142	118	111	132	105	110	102	139
Total related to Herbicides	45%	39%	73%	43%	29%	41%	42%	58%

* The APWSS 2009 Conference was delayed until 2010, because of security concerns in Pakistan

Adding to the above themes, the 23rd Conference (2011), in Australia, mooted the subject of managing weeds in a '*Changing World*', acknowledging the various changes occurring, not just in the weed floras, but also how we approach weed management. Issues discussed broadened to highlight the full integration of the benefits of herbicides, biological control, and other tactical tools with catchment-scale management tools (such as GIS-based mapping and climate change modelling).

The strategic approach to weed management explained the importance of closing the door on the introduction of risky species by influencing the nursery industry, weed scouting, and surveillance, across large areas, such as watershed catchments, as well as rapid responses to new weed infestations, all of which are areas of weed management well developed in Australia and New Zealand. Nevertheless, reflecting the growing concerns, developing herbicide resistance development and its management were common topics in 2011.

Presentations in the New Millennium also broadened the scope of Weed Science in the region from agricultural weeds to include environmental weeds. Weeds in non-agricultural areas had not been a priority topic at APWSS Conferences in previous decades, perhaps because the initial focus had long been on controlling agricultural weeds. Other highlights during this period are as follows:

- Global agrochemical companies continued introducing new herbicides to the region, although the pace of new discoveries was slow. The 18th Conference in China (2001) promoted several new herbicides: cyclosulfamuron; flumioxazin; ethametsulfuron; The Beijing Conference also had a strong 'ecological' bent, as suggested by the theme, including allelopathy and biological weed control, with

63% of papers presented promoting the integration of ecological knowledge into practical control. The 19th Conference in Manila (2003) continued the ecologically based weed management theme (more than 60% of papers). Among new herbicides, carfentrazone was introduced to region in 2003.

- Herbicides again dominated the 20th Conference in Vietnam (2005) with about 73% papers presented discussing various aspects of chemical control, under the central theme - 'Six decades of Weed Science since the discovery of 2, 4-D'. The host-country, with heavy reliance on herbicides for maintaining agricultural productivity, may have also influenced the focus. Penoxulam and flucetosulfuron were introduced as new herbicides to the region in 2005, and 'utilization of weeds' emerged as a new category.
- As with the 2001 Conference, the 21st Conference in Sri Lanka (2007) had somewhat of an ecological focus with more than 50% of papers covering weed surveys, environmental weeds, the biology and ecology of known species, and integration of some weed control practices, including allelopathy. Herbicides, particularly, for upland crops, remained a constant theme. Strongly reflecting the host country's interests, the 22nd Conference in Pakistan (2010) focused on managing weeds in various upland crops, particularly through the integration of cultural methods and allelopathy.
- As shown in Table 5, since 2001, there has been a decline in the total number of papers on herbicides (average of 46% for eight Conferences, the least being 29% in 2010). However, on average about 20-25% of those herbicide papers were on resistance development and management.

APWSS –Perspectives for the Next 50 Years

Our review finds that the region was slow to appreciate that most weeds can only be managed, not fully eliminated, and this requires a strategic approach. IWM had been in practice in the advanced economies since around late-1980s. Although cultural weed control and biological control have long been favourite themes at APWSS, demonstrations of the full integration of IWM applications were relatively few in the APWSS proceedings, until the New Millennium. This shows slow adoption, possibly due to lack of engagement from governments. We would also say that most Asian-Pacific countries had been largely focused on 'tactical' weed control, as opposed to 'strategic' control, until this fourth decade.

The strategic approach, including the full integration of all available techniques – knowledge of weed biology and ecology, prevention of spread, eradication, containment, and asset protection activities – at times and places that make them most effective and efficient, took time to develop. Despite studies on the biology of individual weeds, most research in the region tended to avoid asking critical questions, such as: *Why are these weeds here? What factors are at play?* Perhaps, the focus on herbicides for at least three decades, and their undoubted short-term success, has had a negative effect of stultifying the development of the 'science' in Weed Science, in the region. Perhaps, herbicides also gave the erroneous impression that weeds can all be eradicated, rather than managed, as the situation requires.

We believe that managing weeds, reducing their negative impacts, and even attempting to eliminate them from farmers' fields, as required, have been consistent goals in Weed Science. This, we believe, is critically important to the economic prosperity of the region, through increased production of food and fibre, as well for managing the unique biological diversity and somewhat fragile environment of heavily populated, individual countries. The number of herbicides–the major driving force of modern weed management–which stood around 70 in 1967 has risen to more than 300. Yet, weed problems have continued to increase in the region, as attested by APWSS Conferences. Our approach to weed control has evolved from relying only on herbicides to more integrated and holistic weed management.

However, it needs little emphasis to realize that weed management is only one aspect of securing food for future generations, within a sustainable future environment. An often-heard comment (excuse?) at APWSS Conferences is that Weed Science gets very little attention from governments, and is poorly funded because the contribution of agriculture to the economies of our region (percentage Gross Domestic Product, GDP) is relatively small. For middle-income countries of our region, and emerging economies, the range is a low 8% (Sri Lanka) to a high of 25% (Pakistan). The higher value is comparable with the average for all 'Least Developed Countries' in the world (as per United Nations), which is 26%[25].

Whilst instantaneous measures of agriculture's contribution to a country's GDP may be useful to economists, it has little relevance to ecological sustainability. The market has a tendency to dramatically revalue essential resources when they are in short supply. For example, freshwater – a finite and vulnerable resource, essential to sustain life, development and the environment – is usually undervalued until supply is disrupted. Food will follow closely on its heels. It also needs to be emphasized that in many developing countries, although the contribution of agriculture to GDP of a country may be low, more than 50% of the population still depend on agriculture and related activities, and most of this population is poor.

Nevertheless, the comparison with advanced economies (Japan, Korea, Australia, and New Zealand) is stark. For example, only New Zealand has an agriculture output within the above range. As a percentage of GDP, New Zealand's agricultural output was 9.38% in 2010, and this decreased to 6.38% by 2014 (latest available figures) showing an economy moving away from agriculture. Australia and Korea are somewhat similar (around 2.5%, even with a population difference of 2:1 in favour of Korea); while Japan's agricultural, output is only 1.1% of GDP, which is lower than even North America (Canada 1.8% in 2013; and USA, 1.25% in 2014). These facts reveal about functioning of those national economies.

Our view is then, broadly, a general decline in agriculture as an income-generating endeavour, as part of the national economy is evident for both developed and developing countries. With regard to managing weeds, encumbered by declining budgets in all countries, not much has changed in the approaches to management of agriculture and environment in the last two decades, apart from the rapidly growing community interest in the impacts of climate change. Communities in many Asian-Pacific countries have also been stirred by the introduction of genetically modified organisms (GMOs), particularly, herbicide-tolerant crops, and their potential effects on traditional production systems. Whilst efforts continue to reduce the amounts of pesticides and herbicides used in agriculture, as a safeguard against residues in food and the environment, the development of herbicide resistance in weeds is already a major concern in the region. These and other challenges will influence Weed Science in the region, as well as other related disciplines.

In the following sections, we highlight some pressing issues that would surely influence the future of Weed Science, as a discipline, and the region, as a whole.

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[25] Agriculture (with value-adding) as % of GDP in 2016 – Australia (2.61%); Bangladesh (14.77%); Cambodia (26.66%); China (8.56%); India (17.35%); Indonesia (13.45%); Japan (1.1%); South Korea (2.2%); Laos (19.48%); Thailand (8.34%); Vietnam (18.14%); Malaysia (8.65%); Myanmar (28.2%); Pakistan (25.23%); Philippine (9.65%); Sri Lanka (8.21%); New Zealand (6.8% in 2014); Source: World Bank Data; accessible at: http://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations

The Population Challenge

By 2025 AD the global population (currently, 7.514 billion) is expected to reach 8.5 billion. Of this, 83% will be in developing countries (Presently, there are 1.403 billion people in China; and 1.284 billion in India). Although the population growth rate has declined from a peak in 1963 (2.1%) to the current 1.13%, there will be more than 9 billion humans on the Earth by 2038. While the rate of growth has steadily declined, population growth will continue beyond 2038. Most would agree that one of the greatest future challenges is to increase food production for this humanity, in geographical areas, where productivity has already declined.

The challenge is actually to increase food and fibre production in a sustainable manner, while maintaining life-sustaining ecosystems. Therefore, particularly in developing countries, a negative attitude towards any group of plants, including weeds, is a mistake that we cannot afford to make. In order to alleviate socio-economic hardships, and to conserve biological and cultural diversities, it is necessary to build on existing links between people and biological resources. The success of this depends on accommodating local knowledge and priorities of communities, with some trade-offs between development and conservation. The ultimate goal must be for the present generation to be 'custodians of landscapes' instead of being relentless exploiters and this requires positive appreciation of all plant resources.

Weeds and Biodiversity

Given the increasing recognition of biodiversity values of weeds in farming landscapes, the issue of *which weeds to control and which ones to live with*, is looming as an important aspect in our region as well. From European perspectives, Clarke (2000) noted that in the new millennium, there will have be more demand for weed management practices that control damaging levels of weeds, whilst maintaining beneficial species. Presently, weeds remain a production constraint in agriculture, and a threat to profitability, and hence, considered as having very low or no value.

Sagoff (2005) explained that the term 'biodiversity' was coined in USA, to bring political attention to the goal of protecting species. It is now widely used in ecology to convey the message that nature is a complex matrix of species-interactions between all living forms. However, the tendency of some authors to exclude non-native or introduced species in a given area, including cultivated or engineered ones, from 'biodiversity', has led to confusion (Sagoff, 2005), leading to question: *Are weeds not part of the same biodiversity?*

Biotic interactions between weeds and their environment, particularly, the dependence of animals, such as insects, pollinators, and birds on weeds has been of interest for several decades. Fifty years ago, John Harper (Harper, 1958; Harper *et al*., 1957) used the example of tansy ragwort (*Senecio jacobaea* L.) to illustrate the extensive biotic relationships a weed has in food chains, expressing the view that Ragwort control in agricultural fields '*might affect all the organisms in the food chain*'.

Of late, in Britain and other European countries, interest in weeds as important components of the biodiversity of farmlands and the landscape has been heightened. This is due to the recognition that by reducing weeds in arable farms, irreparable damage is being done to the biological diversity in vast areas of agricultural and semi-rural landscapes. An ecological rule is – in diversity, there is strength. Robinson and Sutherland (2002) reported that most arable weeds in British farms have declined since the 19th century, and losses have accelerated towards the end of the 20th Century with intensification of agriculture. A number of farmland birds have declined (Krebs *et al*., 1999), and invertebrate animals have also shown similar declines. Changes in agriculture, including the intensity of farming, changes in drainage, introduction of new crops, changes in sowing season, and increased use of agrochemicals (fertilizers, herbicides) have all been implicated. The development of more ecologically sustainable farming systems, maintaining some weed species within crops is a new challenge for Weed Science (Marshall, 2002; Marshall *et al.*, 2003; Storkey, 2006; Storkey and Westbury, 2007).

In this discourse, weeds are recognized as not just bystanders in the biological diversity of nature, but as critical components. Managing weeds within the crop to support biodiversity inevitably involves the risk of reducing crop yields and the long-term build-up of problem weed communities. However, a pragmatic approach to reconciling biodiversity with crop production is to manage low populations of 'beneficial' weed species. As opposed to 'invasive' weeds, beneficial weeds are defined as species that provide low levels of competition with an arable crop and has potential value as a resource for higher trophic consumer groups.

Marshall *et al*. (2003) recently identified a range of tolerable weeds on three basic attributes: (a) the number of insect species associated with them; (b) the number of and the importance of weed seeds in the diet of farmland birds; and (c) a competitive ability index. Their evaluation resulted in some species, such as annual meadow grass (*Poa annua* L.) and prostrate knotweed (*Polygonum aviculare* L.), as being more important for biodiversity in arable systems than others like black grass (*Alopecurus myosuroides* Huds.) and speedwell (*Veronica persica* Poiret). The challenge in the Asian-Pacific region also will be to apply such methods to select species that may be tolerated to achieve a sustainable ecological balance.

Storkey (2006) extended this approach to identify groups of weeds that are similar in terms of the balance between their competitive ability and biodiversity value. This 'trait-based' analyses, based on attributes, such as seed weight, flowering time and maximum height, identified two beneficial groups that could potentially be managed to reconcile biodiversity with crop production. To illustrate, these were: (a) spring germinating species, including fathen (*Chenopodium album* L.), lady's thumb (*Persicaria maculosa* Gray) and *Polygonum aviculare*, and (b) autumn germinating species, including *Poa annua*, groundsel (*Senecio vulgaris* L.) and chickweed (*Stellaria media* (L.) Vill.). Species in this latter group have a growth form that is complementary to the crop. That is, they generally grow below the crop canopy, forming an understory, and maturing early, avoiding crop competition late in the season. As a result, they utilize, in part, resources that the crop is unable to capture, and the total productivity of the system is increased.

Storkey suggested this example as a possible 'win–win' situation, where a certain amount of weed biomass is maintained, and is associated with minimal loss of crop yields. Reconciling crop production and biodiversity conservation will be a key aspect of Weed Science for habitat management in future farming landscapes in both developed and developing countries.

Climate Change Impacts on Weed Distribution

In the coming decades, the trend of increasing concentrations of greenhouse gases and enhanced greenhouse effect presents serious threats to both agriculture and natural ecosystems. Climate change is therefore likely to be the biggest challenge faced by the human society. The Inter-governmental Panel on Climate Change (IPCC, 2014) Report states that, on a global scale, the number of cold days and nights has decreased, with a concomitant increase in the number of warm days and nights. Reporting that the frequency of heat waves has increased in large parts of Europe, Asia, and Australia, IPCC's conclusion is that human influence has contributed significantly to the observed global-scale changes in the frequency and intensity of daily temperature extremes, since the mid - 20th Century. Although there are still skeptics, our position is that we appreciate the indisputable scientific evidence, gathered, analyzed and interpreted by scientists, which point to anthropogenic contributions.

The responses of crops, weeds, or natural vegetation communities are inexorably linked to the climate modifications that humans have exacerbated. The impact of climate change upon weeds includes changes in landscape features, and creation of abiotic, suitable habitat 'hotspots', which will allow some species to spread more widely. To illustrate, in Australia, climate change modelling shows increased vulnerability of south-west and south-east Australia to invasion by several tropical weeds, broadly indicating a southern (poleward) movement of those species from the wet (warm) tropics (Duursma *et al*., 2013). Learning from Australia and other countries, the subject needs attention in the developing Asian-Pacific countries.

Herbicide Resistance in Weeds

Whilst modern herbicides have revolutionized weed control over the last 70 or so years, herbicide use has led to high selection pressure for herbicide resistance in many weeds. It is a normal and predictable outcome, as part of natural selection, first predicted by John Harper in 1956 (see quote below).

> *"…This discussion on weed ecology emphasizes that the weed flora of a region may undergo striking changes over long periods. Nevertheless, weed populations possess important properties of stability, which make it unlikely that the use of herbicides will lead to major weed problems from previously minor, but herbicide-resistant, weeds. Susceptible species may develop resistant strains, and action must be taken to meet this danger..."* (Harper, 1956)

Herbicide resistance is the inherited ability of an individual plant to survive and reproduce following a herbicide application that would kill a wild type individual of the same species. Reviewing the subject, Ian Heap (2015) suggested that herbicide resistance is a particularly challenging problem, exacerbated recently by the decline in herbicide discovery, reduction of available herbicides, due to the banning of many, based on safety to humans and the environment. According to the International Survey of Herbicide Resistant Weeds, as of 10 July 2017[26], there are currently 480 unique cases (species x site of action) of herbicide resistant weeds globally, with 251 species (146 dicotyledons and 105 monocotyledons).

Weeds have evolved resistance to 23 of the 26 known herbicide sites of action and to 163 different herbicides. Herbicide resistant weeds have been reported in 91 crops in 69 countries. North America remains the 'hotspot', followed by Europe, Australia, Asia, and South America. Not surprisingly, regions that do not use herbicides intensively, such as Africa, have few problems of herbicide resistance (Heap, 2015).

Of the 16 sites of action, so far determined, resistance to ACCase (acetyl co-enzyme A carboxylase), ALS (acetolactate synthase), and EPSP (5-enol-pyruvyl-shikimate-3-phosphate) synthase inhibitors are among the most common resistance mechanisms (Heap, 2015). These are not surprising to the enlightened weed scientist, as our pioneers pointed out six decades ago (Harper, 1957; Baker, 1965; Stebbins, 1965) that many weeds have an innate capacity to evolve resistance to any weed control strategy used continuously for long periods. The best weapon against this capacity of weeds to evolve under selection pressure is to change its direction, as often as possible, and utilize a diversity of weed control strategies to destabilize evolution (Heap, 2015).

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[26] The international survey of herbicide resistance weeds. Online at http://weedscience.org/

Genetically-modified Crops

A genetically modified organism (GMO) is one that has been modified by gene technology; or an organism that has inherited particular traits from another organism (the initial organism), being traits that occurred in the initial organism because of gene technology. Genetically modified (GM) crops have resulted in a major shift towards less emphasis on new herbicide research. Therefore, investments in research to discover herbicides with new modes of action have decreased dramatically.

For the major crop of our region, *viz*. rice, recent commercial developments have taken place for three herbicide resistant varieties: Clearfield® (imidazolinone resistant), Roundup Ready® (glyphosate resistant) and Liberty Link® (glufosinate resistant), with genes for resistance derived from different sources. The adoption of herbicide-resistant transgenic biotech crops over the past two decades has added a new dimension to the field of Weed Science. Some Asian-Pacific countries have enthusiastically accepted these, which others are considering benefits against losses. Even with well-developed guidance resources around the use of GM herbicide-tolerant crops, including the management of any resistant weeds and volunteer plants, the public is not entirely convinced of the long-term safety of the GM technology. This presents a significant future challenge to the Asian-Pacific countries, because of the aggressive push towards wider adoption in the region, based on the potential to increase food production, and food security.

Weed Research

Weed research aims to answer essentially the following questions: *which weeds are the most significant in terms of adverse impacts on agriculture or the environment, and why (in terms of biology and ecology); and how to successfully manage them and reduce their adverse impacts*. As we have discussed in our paper, weeds in agriculture are a consequence of how we grow food; those that are problematic in other situations, do so because they are adapted to capturing vacant niches created by disturbances (such as land clearing). Added to this would be colonizing species, previously denied access to an occupied ecological niche by geographical isolation, or climatic conditions.

We firmly believe that studying both the ecological and human components of agroecosystems should allow weed scientists to construct management strategies that more fully address agricultural production, environmental consequences, and social implications of weeds and weed control. However, as we look back at the past 50 years, it is evident that *our understanding of weeds lags a long way behind practices of weed control*. Nevertheless, we appreciate that, in many situations, one cannot wait until all factors related to an individual, potentially problematic species are understood, before taking action.

Literature indicates that most of serious species are exotics that were introduced into our region. Many have come into the Asian-Pacific region from elsewhere in the world, arriving first as desirable plants introduced by humans (i.e. new crops, pasture species, cover crops, ornamentals), or just as hitch-hikers, as goods and commodities get moved around. Our region has been greatly affected by such exotic species. The region's weed floras are also complemented by locally important species, which can tolerate and thrive in disturbed situations, mostly caused by humans (such as cultivation, land clearing, and deforestation).

We understand the biological attributes of weeds more clearly now than ever before – thanks largely to Herbert Baker, Ledyard Stebbins, Jack Harlan, John Harper, and other pioneers of our discipline. However, part of our all-important weed research agenda must aim at understanding the key factors that are driving the proliferation of weed species, so that we can take action to mitigate them, firstly, at a local level, and then in the region. We are aware that this is easier said than done!

Intensive research into the biology of major weeds will surely lead to their long-term effective management. There are many examples from the Asian-Pacific region of detailed studies forming the foundation for optimizing control options. Unfortunately, this enlightened attitude is not widespread in both developed and less-developed economies. The common practice in most countries has been to deploy whatever means at hand, and reactively overcome a weed problem. When successful approaches (i.e. integration of the primary methods of weed management - weed hygiene, cultural, physical, biological, and chemical-based methods) are not utilized, failure is guaranteed. We also find much of the academic-sounding weed research in the region has little practical value, because of flaws in articulating the initial research question.

As we have discussed, much has happened in Weed Science research within the Asian-Pacific region since the Society held its first Conference in 1967. The world now has an impressive armoury of new herbicide chemistries, herbicide safeners, and application technologies. We also have current problems, related to over reliance on herbicides for weed control, which should not continue. In the years to come, new challenges may arise. From our point of view, the priority for weed research in the Asian-Pacific region should be to support research that aims to understand the mechanisms of weed impacts that will then lead to better approaches to weed management, which can be adopted readily in our region.

Broadly, the priorities should include the following:

- Understanding the impacts of weeds on ecosystems, and specifically, factors governing invasions across large landscapes by multiple weed species, as well as individual species;
- Increasing the research capacity in biological control, as this appears to be the best control option for many widespread and abundant weed types;
- Assessing opportunities for the integration of both ‘weed-led’ and ‘site-led’ weed management with broader natural resource management (NRM) objectives; this includes management of biodiversity, fire, pest animals and livestock and protective native ecosystems;
- Increasing the understanding of interactions between invasive plant species and their invaded habitat, including synergistic effect son natural ecosystems and biota.

Having come through the early decades where the focus of most weed research was on herbicide efficacy testing, we have now moved well beyond herbicides. Weed research now has to focus on policy solutions, stakeholder engagement and large-scale vegetation and landscape management, as well as ‘site-led’ and ‘weed-led’ approaches, encompassing integrated weed management. Since around 2000, weed research in developed economies has focused on understanding invasion biology; invasion pathways and the invasion process (see Williamson, 1995). This is commendable, as an increased understanding of these aspects will lead to weed researchers better appreciation of the ecological consequences of plant invasions, including the impacts of weeds on broader biodiversity of both agricultural and non-agricultural situations, and climate change. A move of Weed Science in this direction is inevitable and desirable.

The reality of many pest/weed management problems in the field is that the level of complexity requires multidisciplinary teams to develop effective solutions. Consequently, we suggest that the success in securing funding for future weed research lies in weed scientists in our region developing strong collaborations across disciplines (as opposed to addressing weeds from a weed control perspective only, with nominal references to other disciplines). Collaboration, we hasten to add, has been not easy across the Asian-Pacific countries, because our ‘Science’ does not exist alone, but is strongly influenced by the sensitive geo-politics of our era.

Prospects for Weeds as Bio-resources or Utilization as a Management Tool

Much has been written about negative impacts of weeds in many countries. However, this view is not universal, and there is increasing interest in the values of weeds as an essential component of the human-modified landscapes. The use of weeds as bio-resources and/or their utilization as a management tool has not been fully realized in the Asian-Pacific region, despite the extensive use of weeds as biological resources (as food, medicines and raw material for various uses) by the region's populations (see Chandrasena, 2007).

Developing a healthier attitude towards weeds and *Nature* appear critical for our region. These are most reflected in the Permaculture movement[27], which originated out of the Land care movements in Australia in the 1970s. Coined by the founder - Bill Mollison, a biologist, the term permaculture is a portmanteau of 'permanent agriculture' and 'permanent culture'. Its primary strategy, accepts a greater role for trees, perennial plants and fast growing species to stabilize degraded, human-modified landscapes. The movement involves a life-style change as well, where people are assisted to become more self-reliant through the design and development of productive and sustainable gardens and farms.

However, our view is that a foray into permaculture goes way beyond what Weed Science colleagues, such as Miguel Altieri, Matt Liebermann, and others of that ilk, envisioned and promoted as 'agro-ecology' (see Altieri, 1995; 1999 and Altieri and Liebman, 1988). We need to absorb from the philosophies of the permaculture movement, only what is directly relevant to our Weed Science community. Instead of creating 'gardens of Eden', the pragmatic approach would be to reflect on our relationships with Nature. From the Weed Science viewpoint, permaculture is not far removed from a large-scale revegetation strategy, its foundation being the use of plant species consonant with a particular area; and *mimicking what nature does*. Notwithstanding other sustainable elements (i.e. producing food locally with minimal outside inputs, creating healthy ecosystems, building soil, constructing housing using local, renewable resources, ending pollution, erosion and degradation of landscapes) colonising plants get a 'fair go' in this framework.

Weeds are not condemned even implicitly; instead, the permaculturist's view is that every plant has its uses, and weeds are no exception. An often-used slogan in the movement is '*one person's weed is another's medicine or building material*'. Although the number of people committed to the permaculture lifestyle is still minuscule, its attitudes, favouring sustainable land use, resonate with the view that plant resources should not be devalued. To many Asian-Pacific societies, it is a practically reality to have austere life styles!

Agro-ecological or permaculture designs are intended to reach noble goals, namely, improved living systems, which are both economically and ecological sustainable, and are *'in tune'* with the locally available biodiversity. However, to be sustainable in any country, these approaches need primarily to meet the aspirations of landholders and farmers and, secondly, to contribute to meeting the broader environmental and socio-economic and political agendas of governments.

We are aware of other interests growing in the region, such as '*Chemical-Free Weed Control*' in Australia[28], which is essentially a part of the growing popularity of the pesticide-free farming systems. Pesticide free farming is an area that requires the attention of weed scientists, because managing weeds in these

[27] https://permaculturenews.org/what-is-permaculture/

systems depends on depleting the existing weed seed banks with non-chemical methods, and preventing any harmful build-up of weeds that do not serve much of an ecological function near the crops being grown. The justification for more scientific investigations into appropriate weed management methods and promoting the development of chemical free farming is the Asian-Pacific region lies in its market potential. For example, in USA alone, the total U.S. organic product sales in 2016 reached nearly $50 billion. Organic farming has averaged double-digitgrowth over the last five years[29].

In a strategic approach to managing weeds, we wish to promote a greater recognition of the utility of these plant resources. The summary condemnation of plant taxa that we may not like to have in a particular situation, or enterprise, is not a sensible way to approach a somewhat complex problem, largely created by man. A much broader appreciation of the useful attributes of weeds will allow us to develop applications that could improving the human condition. Weeds are clearly highly successful plants, largely due to superior colonising ability and competitiveness. These attributes can be very useful, not just in repairing damaged ecosystems, but also in providing food and fibre for all animals, including humans in the future.

Linking Weed Science Knowledge to Practical Action

A responsibility for our Society, as well as professional weed scientists and land managers is to adopt innovative approaches to managing weeds. Weeds are ubiquitous, in that they do not respect artificial boundaries, such as fence lines, which demarcate a cropping field from adjacent weed-infested areas. Weed management programmes in the future will have to be re-aligned to meet the needs of maintaining the balance between economic, social, and environmental concerns. This requires a holistic, risk management approach, and an analysis of the ecological, biological factors, and physical factors, within farming or non-farming landscapes, along with interrelated components. Weeds are only one constraint for agricultural production, but we need to be mindful of other interactions as well.

Published literature and the vast collection of APWSS Proceedings themselves indicate that, broadly, there is a good baseline of knowledge on weed issues and weed management frameworks available in the Asian-Pacific region. Yet, there are still wide differences in how weeds are managed in each country. These differences reflect not just economic disparities, and possibly, levels of education, but also government funding and social priorities. For instance, poverty alleviation and food security are the highest priority in developing countries of the region, whereas, the developed economies are struggling with other social issues (i.e. ageing populations and labour shortages in Korea and Japan). Land clearing, and soil erosion, due to over development are common problems, as are other environmental concerns (e.g. pollution of waterways).

In all countries alike, we find deficiencies in funding for on-ground weed management programmes and weed research. Australia and New Zealand are classic examples in this regard, where this funding has been in sharp decline over the past two decades, except perhaps for managing herbicide resistant weeds. The decline in funding has necessitated community involvement for implementing community-led weed

[28] A series of 'Chem-Free Weeding Workshops' were held in Australia, in 2014-15, organized by Dr. David Low (E-mail: david.low7@bigpond.com), promoting a public discourse on non-chemical weed control. Several government agencies supported the workshops, valuing the insights they provided into current public perceptions of herbicide pollution and health issues (Source: https://www.eventbee.com/v/chemfreeweedingsydney2015)

[29] Source: Organic Traders Association, OTA (https://www.ota.com/about-ota)

management programmes, with governmental institutions often taking only a 'backroom' administrative role. In this environment, recognition of the importance of human culpability in creating environmental problems is often lost. The public also has limited power to change the way environmental management is practised.

The fact that we have made errors in introducing exotic plants for perceived benefits to countries, where they did not exist before, is evident. In taking action to reduce this risk, Asian-Pacific countries can certainly benefit from the experiences of Australia and New Zealand. These 'islands' have developed excellent 'border protection' policies and Weed Risk Assessment (WRA) frameworks, which have been globally adopted (see FAO, 2011). Key long-term strategies that are likely to minimize the negative impacts of weeds in the Asian-Pacific region include preventing the introduction of species that can become new weeds in the region, through risk assessments and strict regulations of plant imports, bio-security, and other prevention methods.

Education, Extension and Information Services

Extension is one of the most important processes in Weed Science, since it serves to inform the end user – usually, the farmer – about which weed control methods may benefit production, while safeguarding the farming environment. However, farmers are not the only ones who need to be informed. Decision makers, such as politicians, administrators and the public also need to be accurately informed of the importance of managing weeds and the methods appropriate for the task. As John Swarbrick (1991), an APWSS stalwart suggested, successful extension requires the receiver to have confidence in the giver of that information. Whatever the topic, the extension officers need to have the right attitude, background, and culture to enable a comfortable transfer of information to farmers or others. In this regard, training in Weed Science, at the level required, is crucial. Several APWSS countries have been active in promoting such training of extension officers, as evident in the activities of our affiliated societies.

There are now a several weed control technologies available in the Asian-Pacific region. As an example, in the case of direct-seeded rice, available technologies include cultivar selection; the use of low rates of herbicides; timing of flooding of fields and growth stages of crops; herbicide rotation to prevent resistance development; crop residue management for weed control; stubble burning to reduce weed seeds (see Rao *et al*., 2007). The Australian '*Rice Check'* package is a good example of how farmers may be introduced to a prescribed series of actions to follow, in order to maximize crop yields (see Lacy *et al*., 2000).

'Ricecheck' is a rice production prescriptive package with simple and objective recommendations. Its adoption was partly responsible for Australia's consistent highest rice yield per hectare (ha), through the 1970s and 1980s. The package shows how farmers should take into account water availability and local weather patterns, when they take certain actions at certain times in the growing season, and continually monitor and check their crop. The benefits of observing, checking, and recording crop data is that crop growth and management actions can be directly related to the yields and grain quality benchmarks.

We believe that successful Weed Science extension needs to adapt such crop and/or cultivar-specific, technology packages to local conditions and practices. Integrated weed management packages are not likely to be adopted by farming communities, unless weed scientists and extension workers ensure that their recommendations are practicable 'on the ground', within the environmental, socio-cultural and economic conditions and constraints of farmers and non-farming communities in our region.

The importance of local research and demonstration trials cannot be overstated to achieve longer-term success. In many situations, adoption of a good weed control method will require innovation, which could be some modifications and or integration of the available approaches.

Reviewing the APWSS literature, it is evident that agriculture in our region varies from highly industrialised systems to peasant systems; from agriculture with large areas of monoculture cropping to small areas of shifting cultivation and mixed cropping. Some of the sophisticated, more productive systems require high-energy inputs (mechanical or chemical energy), while other systems continue to rely on human and animal power and low inputs with modest or low productivity. Production methods, based on highly mechanized, high-technology-based methods (*viz*. 'western' agricultural methods) may not be appropriate for agriculture of a good proportion of the Asian-Pacific region. Our proceedings have often highlighted that farmers of the Asian-Pacific region rely on governmental and non-governmental sources for information, advice, credit and support, because they cannot afford complex support systems (such as environmental monitoring systems; GIS-linked, web-based, information systems for predictions of likely local weather, or water availability).

As highlighted by Swarbrick (1991), failure to realize the wide gulfs between existing production systems, will lead to waste and frustrations in all aspects of Weed research, education and extension. The wide diversity of people and cultures in the Asian-Pacific region means that '*one-size fits all*' solutions will not work. As a Society that has already made a mark in Weed Science and weed control research, APWSS also has a responsibility to deliver research, which may not be of our own choosing, but which are 'appropriate'. The process to do this successfully is consultation, discussion and information exchange through existing and future networks. Evolving technologies allow scientists to connect with each other much more freely and quickly. Casting an eye on the future, as an over-arching regional Society, APWSS must continue to energize the member countries and their local, affiliated Societies to engage with all stakeholders in this regard.

As previously stated, it is also important to recognize that weeds are not the only constraint to agricultural production and *Weed Science does not stand alone*. Securing food, within a safer environment for future generations will come only through the application of scientific knowledge across various disciplines. Therefore, weed scientists must keep in constant touch not only with each other, but also with other applied scientists, who provide research, information, education, and extension in other disciplines, such as plant breeding, agronomy, entomology, plant pathology, modelling, water science, and climate science.

International Collaboration

Looking back at the past 50 years, it is evident that APWSS has been important for international collaboration, and for connecting people in our region with each other, and providing a forum for exchange of Weed Science information. The biennial APWSS Conference is now internationally recognized as an important forum for both cultural exchange and for sharing of practical experiences in weed control. Additional symposia, workshops and networks, such as the *Parthenium weed Network*, have assisted in linking young weed scientists in the region with industry, internationally recognised institutions, and senior scientists. Several books and monographs, sponsored by APWSS, and written by members have strengthened international exposure of our Society, and made weed scientist of the region known more widely.

A Final Word

As a final word, we ask again - *what have we learnt from Weed Science in the past 50 years? Do we really know why we have weeds? Do we know why they behave in the way they do? Are all weeds evil – as they have been generally regarded to be? Do we know, with any degree of certainty, how much of crop yield losses and other losses can be attributed to weeds?* As significant as the accomplishments have been, we are of the view that the full potential of Weed Science is yet to be realized in the Asian-Pacific region. While we re-iterate that *Weed Science is not just about weed control*, we hope the maturity of the discipline would help show the way in shaping and improving our management of all natural resources, and not just agriculture.

Our review found that developments of weed control practices over the past 50 years have indeed, resulted in major improvements in how we deal with weeds in nearly all of the Asian-Pacific region's countries. As weeds are an important component of agricultural systems, increased crop yields, obtained in recent times, can be partly credited to improved management of weeds. In addition, all over the region, there appears to be a higher degree of confidence in addressing weed-related issues in 2017 than in 1967. We attribute this, at least partly to the efforts of the APWSS, and membership, who have diligently strived to uphold the primary objective stated in 1967: "…*To promote Weed Science, in particular in the Asian and Pacific regions, by pooling and exchanging information on all aspects of Weed Science*…" Yet, we are acutely aware that Weed Science is the most poorly funded discipline within the broader field of crop protection.

Full integration of the gamut of tactics and techniques that can be used to reduce the negative impacts of weeds should be our primary goal in weed management. Perhaps, a qualifier may be added – *Only when and where there is a problem with weed abundance*. Only then will the potential benefits of weed control be sustainably realized. To achieve this goal, we need a complete understanding of weed ecology; the relationship weeds have with crops (in the agricultural fields), their interactions with other plants (natural communities) and the environment Although much is known about these relationships, this knowledge is often incomplete for major species, particularly, under changing circumstances imposed by increased disturbances and climate change. In this regard, the Asian-Pacific Region is no exception to other regions.

Radosewich and Holt (1997) pointed out that: "…*any plant can be a weed and no plant is always a weed…"Understanding weeds* still lags a long way behind our inadequate attempts to control them. We believe that at least our region must lead in recognizing the special attributes of these species, as important components of the earth's biological resources and their role in ecological succession. Although weed abundance brings them *occasionally* into conflicts with humans, our review of the literature from the Asian-Pacific Region supports the viewpoint that *not all weeds are bad all the time*.

Given this, we believe that human populations and societies in the Asian-Pacific Region will benefit by focusing on a more holistic weed management paradigm, which includes resolving conflicts with weeds amicably, and perhaps even co-existing with them (See Chandrasena, 2014; 2015). Instead of continuing an unsustainable war against weeds, perhaps a better approach for the region as a whole would be to train the next generation of weed scientists to develop a healthier attitude towards weeds, treat them as biological resources, rather than enemies, and manage them, as appropriate to the situation. We acknowledge that weed occurrence is inevitable, where human habitation and disturbances continue, and there is no simple remedy for the problem of weed persistence in its many manifestations. However, we re-iterate that *weeds are a symptom of inappropriate land-use*; for instance, over-development of land for agriculture, including vegetation clearing, conversion of grassland ecosystems for pasture, clearing of lands for human settlements and linear infrastructure, such as rail and road, and similar human-caused disturbances. The more we understand this, the better we will be at planning how to manage plants that thrive under such disturbances. This, we believe, should be a primary message of APWSS, going forward.

When seen through a broader lens, *Weed Science can be a powerful tool to understand Nature and connect with it*. If the weed scientists of our region look closely about what they are engaged in, they are likely to understand the critical inter-dependency between organisms (including all plants and all animals, including humans) and the environment. We now live in a world, separated so much from Nature, due to our busy lives and aspirations, and confusion through the pace of technology change.

Perhaps, enjoying a moment with weeds, which do not ask for much, other than to be understood, but know how to thrive in inhospitable environments, will open our eyes to the benefits and potential of weeds. Perhaps, this understanding will also lead us to respond more effectively to some of the major challenges humans face today: a burgeoning population, poverty, inadequate energy and food, negative impacts of unmitigated resource exploitation, urban developments and disturbances, environmental pollution and other forms of degradation and relentless growth. In conclusion, we re-iterate, w*eeds are certainly not the culprits if we cannot produce enough food; reduce poverty, or prevent the degradation of our environment*. Rather, it is our lack of understanding of how to live with weeds and manage weeds, that is limiting us.

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Weed Science in the Asian-Pacific Region: Present Status and Experiences

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Abstract

The exclusion or management of weeds has been a continuous struggle throughout the history of agriculture and native ecosystem protection in the Asian-Pacific region. Despite significant developments in the methods used, weeds still reduce productivity and profitability by undesirable amounts, and upset the structure and stability of natural ecosystems. The Asian-Pacific region has considerable strengths in many aspects of Weed Science technology and training. However, various concerns, such as the growing need for food due to an ever increasing population, the increasing arrival of new weeds as international trade and travel escalates, the acknowledgement of climate change and its likely impacts upon weed distribution and abundance, and the advent of special threats, such as the evolution of herbicide resistance in weeds and to the adoption of reduced tillage agriculture, have all necessitated the re-evaluation of our current approaches to weed management.

This paper makes an attempt to provide a summary of some of the present problems facing food production and environment protection in the Asian-Pacific region and to review some of the future approaches that may be used to help manage these weed threats. The weed management challenges now facing our region will require weed management systems that are safe for the community and the environment, sustainable and profitable in both the short- and long-term, and adaptable for use in all situations. In the past, the vision and the objective of achieving good Weed Science outcomes in the Asian-Pacific region have been primarily achieved through information exchange at conferences, workshops and training courses, through the Society newsletter and international journal articles and some bilateral research collaborations. The time has come for an increased level of international collaboration to meet these new challenges.

Introduction

Weeds are the biggest limitation to food, feed and fibre production around the globe. In the Asian-Pacific region the prevention and management of weeds has been a continuous struggle throughout the history of agriculture and native ecosystem protection. Despite ongoing developments in weed avoidance and management knowhow, weeds still decrease productivity and profitability, and upset the natural balance of our native ecosystems. In addition, various issues, such as the rapidly increasing global population, the appearance of new imposing weed threats, the impacts of climate change, and concerns for the environment have all necessitated the re-evaluation of our current approaches to weed prevention and management.

By 2050 the Asian-Pacific's population is expected to have increased from the present day 4.2 to reach 6.0 billion. Such a population increase will require, by one estimation, an increase in nutritious food production by 70%. This will place an unprecedented demand upon both agricultural and natural

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ecosystems and their ability to convert the natural and biological resources of light, water, air and soil nutrients into food, feed and fibre for at least another 1.8 billion people and their livestock. A critical issue now is how can we meet this challenge, while faced with little new land available for food production, and in the expectation that our food will need to be more nutritious and that our chosen methods will now have to have low impact upon the environment. The growing demand for agricultural products must be balanced with the need for environmental protection and biodiversity conservation, and we need to do this under an unpredictable and changing climate.

The big challenge facing Asian-Pacific weed scientists and land managers is how to develop weed management procedures for agriculture and natural land systems that are effective and profitable, in both the short- and long-term, sustainable and safe for the community and the environment, and adaptable to cover most managerial situations. This paper will reflect upon four of the main challenges to agricultural production and environment protection in the Asian-Pacific region (*viz*. a rapidly increasing regional population, emerging new weed problems, climate change, and the use of unsustainable farming practices) and discuss a brief inventory of approaches and options that may be used to meet these challenges.

Present problems

The present challenges within the Asian-Pacific region that are causing the most concern to agriculture and are compromising the environment, come from a number of fronts of which major are: 1) a rapidly increasing human population, living longer and demanding more nutritious food, 2) an increasing threat from new, imposing weeds and other pests, 3) a changing climate which is manipulating the abundance and distribution of the weed and pest problems within our agricultural and natural ecosystems, and 4) the use of certain non-sustainable approaches to farming the land and to manage weeds.

The challenges facing Asian-Pacific weed scientists and land managers are those of developing weed prevention and management strategies that promote food security and land protection, which are effective and profitable in both the short- and long-term, sustainable and safe to the community and the environment, and adaptable so they can be used in many situations. The following dissertation will focus on these four main challenges facing land managers and researchers today.

The ever-increasing Asian-Pacific population

By commonly cited estimations, the world population of approximately 7.0 billion will rise to 9.0 billion by 2050, with the largest increases being in Africa and the Asian-Pacific region. It has been estimated that agricultural production will need to be increased by 70% to meet the food and fibre demand by 2050, and to achieve this, further agricultural land will need to be found, or we will need to become more productive on the land we presently use. Within the Asian-Pacific region the current population of 4.2 billion is expected to rise to 6.0 billion by 2050, with the greatest population growth likely to occur in India and China; each country predicted to reach 1.4 billion by 2025. This regional population increase will be the result of both an increase in the birth rate and longevity.

An imperative question is how can we meet this increased agricultural production goal, while maintaining the health of our natural environment? One study has identified a number of possible approaches we might use to achieve this (Marris, 2008). The first of these suggestions is for us to develop better fungal (rust) resistance in wheat (*Triticum aestivum* L.) as this could potentially save 19% of the world's wheat harvest from being lost to plant diseases. Another idea is to turn wheat into a longer-lived, perennial crop, which would require less seasonal land preparation, which in turn will reduce soil erosion. At the same time, the deeper-rooting potential of the perennial plant would mean the crop would require less fertilizer and water inputs, turning traditional cropping land into a highly productive perennial grassland. Alternatively, by using genes from maize (*Zea mays* L.), the photosynthetic mechanism of rice (*Oryza sativa* L.) could be effectively changed from being a C_3 plant to a C_4 plant, creating a supercharged plant with a 50% greater seed production.

It is interesting to note that since weeds are considered to be one of the largest constraints to crop and animal production world-wide, little thought has been given to the possibility of managing weeds better to help foster the required increase in food production. I strongly suggest that Weed Scientist can contribute to raising food production and its quality, but this achievement will come from many small improvements that are more orientated towards site-specific outcomes, rather than from one large change in the way we manage weeds. Before considering possible new improvements to food, feed and fibre production and environmental protection through better Weed Science, it's important to consider the diversity of the weed problems we face within the Asian-Pacific region.

The threat from weeds

Describing the full range of challenges weeds provide us with within the Asian-Pacific region will not be possible in this brief critique. However, some examples can be given of the different kinds of weeds we are now faced with and the different kinds of problems they cause. As might be expected with the change in the land management systems used over the course of time, weeds that were once a problem are now seen as less important today. Alternatively, with these changes in management practices, and because of a changing climate and a more recent greater movement of people and goods between regions, a different weed set has taken the place of the historically important ones.

Historical weed problems:

Around 30 years ago, presentations made at the biennial APWSS meetings were on weeds that are now less of a problem. Weeds, such as barnyard grass (*Echinochloa crus-galli* (L.) Beauv.) and canary grass (*Phalaris minor* L.) were among those that threatened productivity of our rice and wheat cropping systems, respectively. Alternatively, in our aquatic systems, weeds such as Water hyacinth (*Eichhornia crassipes* (Mart.) Solms), Salvinia (*Salvinia molesta*D. S. Mitchell.) and Alligator weed (*Alternanthera philoxeroides* Griseb.) all dominated the discussion on how to develop new management approaches.

In pastures and non-agricultural land, weeds such as blady grass [*Imperata cylindrica*(L.) Beauv.], giant mimosa (*Mimosa pigra* L.) and lantana (*Lantana camara* L.) also posed considerable threats and were the subject of many of our earlier investigations. However, in the current era of significantly increased movement of goods and people around the globe, a much greater threat comes from the accidental introduction of many new weeds, and under climate change several native and sleeper weeds have also emerged as new threats.

The new threats:

Many serious weeds that have arrived in the Asian-Pacific region in recent times are still expanding their distributional range and abundance, and therefore their importance. Colonization of new landscapes through certain natural and human activities have allowed these new weeds to gain a significant foothold in our region. The following are some of that pose the greatest concern:

Weedy rice: For a number of countries in the Asia-Pacific region, and as an example of a weed of primary production, 'weedy rice', or red rice (*Oryza sativa* L.) has now emerged as a new and significant weed problem in our region. First noted in 1988, weedy rice has now become a challenging weed in rice production systems in a number of south, south east and eastern Asian countries. Weedy rice is a form of cultivatedrice, but one that has a shorter life span and a taller stature.

Weedy rice strains produce few, small seeds that shatter easily, before the crop is harvested. The origin of weedy rice is not certain. It may have originated from the reversion of cultivated rice to an ancestral state, or may have come about by the crossing between cultivated rice and a species of wild rice. In most rice production regions, weedy rice has become a problem following the shift from transplanting to direct seeded rice production. In Vietnam, the average yield loss due to weedy rice ranges from 15 to 17%. The close similarity between weedy rice and the commercial varieties prevents the use of many herbicides and the only effective approach to reduce weedy rice infestations is through integrated management.

Parthenium weed: There are many examples of new rangeland weeds that have become problematical in the Asian-Pacific region in recent years. One such weed is parthenium weed (*Parthenium hysterophorus* L.) which not only inflicts losses in rangeland production, but also on crop production and the natural environment. It also causes human and animal disease and these impacts are to be seen in many countries of our region. Outside of its native range of Central America, parthenium weed has spread, with the aid of human intervention, to many countries within our region (e.g. Australia, China, India, Sri Lanka, Bangladesh, Nepal, Pakistan, Bhutan, Malaysia, Vietnam, Korea, Japan, Vanuatu, New Caledonia, Hawaii, Papua New Guinea, Christmas Island, French Polynesia, and Tahiti).

A number of biological and ecological attributes contribute towards this weeds invasiveness, and therefore, various management approaches (*viz*. cultural, mechanical, chemical and biological control) have to be used to minimize the losses caused by this weed. Although, chemical control using herbicides and biological control utilizing exotic insects and pathogens have contributed significantly to its management, the weed remains a major and growing problem in the Asian-Pacific region. Losses due to parthenium weed range from 10 to 100% in rangelands and from 15 to 80% in a number of crops and only through integrated control approaches, can reductions of infestations be effectively achieved.

Mikania vine: As an example of a significant environmental weed, mikania vine (*Mikania micrantha* Kunth. ex. H.B.K) has quickly become one of the most invasive plants worldwide (Lowe *et al*., 2000). For many countries in the Asian-Pacific region, mikania vine has rapidly become one of the most damaging weeds of the natural environment but is also a problem in plantation and field crops. Outside of its native range of tropical America, mikania vine has spread, with the aid of human intervention, to countries within our region (e.g. China, India, Sri Lanka, Bangladesh, Philippines, Indonesia, Taiwan, Brunei, Malaysia, Singapore, Thailand, Fiji, Samoa, other Pacific Islands, Nepal, Bhutan, Vietnam and more recently Australia).

The increase in the rate of urban development and that of human interference has been suggested to be one reason as to why mikania vine has spread so rapidly, between and within countries of the Asian-Pacific region. It is widespread in the Pacific Islands where it is a major weed of sugarcane (*Saccharum officinarum* L.), taro (*Colocasia esculenta* (L.) Schott) and banana (*Musa* spp. L.) crops (Macanawai *et al*., 2012). Losses due to the species can range from 15 to 100% and only through integrated control, utilizing biological, and physical, and chemical control methods can reductions of mikania vine infestations be effectively achieved.

The growing threat from climate change

Climate simulations indicate temperature increases in the Asian-Pacific region will be in the order of 1.0 to 7.0°C by 2070 with temperatures increases more extreme in the arid areas of India, China and Pakistan. Additionally, the climate simulations indicate a rising rainfall concentration throughout much of the region, including greater rainfall during the summer monsoon. Furthermore, winter rainfall is likely to decline in South and Southeast Asia, signifying an increased aridity during the winter season.

The region will be affected by an increase in global sea level of approximately 7 to 50 cm by 2070. Other studies have indicated the potential for more intense tropical cyclones and changes in certain components of climate variability, including the El Niño-Southern Oscillation.

Impact of temperature rise:

In the longer term, gradual warming of the Asian-Pacific region may lead to many weeds of the tropical parts to extend their range into the more temperate parts of our region. This kind of response to climate change may also result in the loss of certain cool-temperate weeds from the more northerly and southerly parts of our region. Species currently restricted to the lowlands may move up into higher altitudes.

For temperature responsive plants such as parthenium weed this shift may be significant and there is some evidence that this weed is moving into higher altitudinal areas in countries such as Pakistan, Bhutan and Nepal. Frost-intolerant species such as Siam weed (*Chromolaena odorata* L.) can also be expected to shift their ranges significantly, further south and further north. There is a high risk that some weed species, at present not considered high priorities, may show increased spread with a rise in temperature.

Impact of changed rainfall patterns:

Changes in rainfall pattern in the Asian-Pacific region are less certain. In the tropical regions there is expected to be an increase in rainfall especially during the monsoon season, with reduced rainfall in the more southerly and northerly regions. In most areas, an increase in extreme events, including droughts, floods, and severe storms, may be expected. Without good information on how rainfall patterns may change, the impact on weeds is difficult to predict. Reduced rainfall may limit or reduce the distribution of many weeds such as lantana and parthenium weed. Reduced rainfall will also reduce the growth of many crops and pastures, reducing canopy cover and increasing patchiness which in turn will favour weed invasion. Increased drought periods combined with occasional very wet seasons, will promote weed invasion, because established vegetation, both native and crop, will be weakened, leaving areas open for invasion.

Impact of atmospheric CO_2 increase:

The present atmospheric CO_2 concentration measured at the International Observatory, Mauna Loa in Hawaii is now over 400 ppm. One prediction is that this atmospheric CO_2 concentration will increase to 800 ppm by 2050 and possibly higher in certain highly industrialized parts of the Asian-Pacific region. At present the Asian-Pacific region is accounting for approximately 50% of the world's total CO_2 emissions, at about 12 billion tons per annum. Increased atmospheric CO_2 concentration can be expected to influence the invasiveness of a number of weed species, particularly those operating a C_3 carbon metabolism, a form of photosynthesis that can greatly benefit from an increased atmospheric CO_2 concentration. This will be especially noticeable in communities that are presently dominated by native or agricultural plants operating a C_4 photosynthesis which will not show an increased growth under these same conditions.

As a result, invasive weeds, such as parthenium weed (Navie *et al*. 2005) and cropping weeds such as wild oats (*Avena fatua* L.) will become even more competitive in the future in an atmosphere of increased CO_2 concentration (O'Donnell and Adkins 2001). However some crops and pasture grasses, may also benefit from the increased atmospheric CO_2 concentration, thus have an increased growth and reproduction potential, and therefore be better able to suppress the growth of weeds. Species that are already present in the Asian-Pacific region could, through elevation of CO_2 concentration, become more aggressive in the future, in areas where they were not problematic before.

Overall, climatic change within the Asian-Pacific region is expected to induce changes in locations where crops are grown and where native vegetation exists. Species, whether crop, native or weed and with efficient dispersal mechanisms (by bird, wind, water or by human vectored pathways) are likely to make these range changes more rapidly than those which do not.

Invasive plants generally have well developed seed dispersal mechanisms, and are likely to spread more rapidly into new areas, quickly exploiting the new climatic conditions that favour new plant establishment. Climate change can be expected to favour invasive plants over established native vegetation, especially if accompanied by an increase in extreme conditions, such as droughts alternating with wet seasons. There is a strong possibility that certain 'sleeper weeds' may be favoured by a changing climate and could rapidly move across the landscape, once certain environmental limitations for their growth are overcome.

The growing threat from other sources

There are a number of developments that are now causing new and extraordinary threats to food, feed and fibre production in the Asian-Pacific region. Those that come immediate to mind are the increased travel, transport and tourism activities that have resulted in an unprecedented increase in the number of new weeds being introduced to, and dispersed through our region, and the over use of chemicals for weed management that has led to the evolution of herbicide resistance in many weed species that are now difficult to control.

Global transfer of weeds:

One new and significant, threat to agricultural production and the environment in the Asian-Pacific is that of internationalisation. Today, more than ever before, people and products are being moved around the globe, and with this are spread many weeds to new areas where they would have never reached naturally. In 2011 the Asian-Pacific region surpassed Europe to become the top exporter of merchandise around the globe and at the same time, imports to our region jumped to approximately 37%. The rapid spread of weeds by human-mediated mechanisms is now the most important mode of weed spread, greater than that of most natural mechanisms, including those of water, wind or animals. Human-induced spread is now considered to be the main reason for new weed incursions globally (Mack and Lonsdale, 2001).

Herbicide resistance:

Prior to the 1940's most weed management around the globe was undertaken using a physical and/or cultural approaches. However, from the time of the discovery of synthetic herbicides there has been a considerable shift away from these more traditional approaches to ones with more reliance on herbicides. This widespread adoption of the chemical weed management techniques has led to considerable changes in weed abundance, distribution and diversity, all within a relatively short period of time.

This shift to chemical farming has not only promoted a species shift to more herbicide-tolerant weeds but also to the evolution of herbicide-resistant weeds. For example, there are now 480 biotypes of weeds, from 252 species that are resistant to one or more herbicides, present in 91 crops in 68 countries, and the number of new cases of herbicide resistance is increasing by 25% per year. In the Asian-Pacific region there are now 245 biotypes recorded as being herbicide resistant in 12 countries with Australia having 84, Japan 36, Malaysia 21, New Zealand 20 and China with 41 (Heap, 2017).

The evolution of herbicide resistant weeds is likely to increase in the Asian-Pacific region, as the commercially available herbicide tolerant crops (cotton *Gossypium* sp. L.; canola Brassica *napus* L.; and maize) are more widely grown. These new crops, genetically engineered to have resistance to non-selective herbicides, such as glyphosate, are expected to provide farmers with a greater capacity to manage otherwise hard-to-kill weeds, such as weedy rice. However, as has been the case in the USA where glyphosate–tolerant crops have been grown for nearly 20 years, many new herbicide resistant weeds are expected to evolve under this new chemical management system in our region.

Future approaches to weed management

As our senior scientists have reminded us, much has happened in Weed Science within the Asian-Pacific region in the past 45 years (see Rahman *et al*. 2012). In recent times, there have been the new exciting developments in herbicide chemistry and application technology, the use of herbicide-tolerant crops and the move towards site specific, integrated, sustainable weed management approaches.

However, there has also been the disappointing encounter with herbicide resistance, and a growing concern for the environment and for human and animal health. We are now entering a new era where new challenges are arising more rapidly, due in part to our rapid population growth, continued movement of new weeds into our region and the impact of climate change. In the future, to meet these new challenges, weed scientists in our region will need to promote research in the following areas;

- The development of new integrated management strategies for important crop weeds (such as weedy rice) which are threatening the productivity of our rice harvest.
- The development of new integrated management approaches for the new or rapidly spreading invasive alien species (such as parthenium weed and mikania vine) which are threatening a wide number of crops as well as the biodiversity of our native communities.
- The development of practical and economic strategies for the management of herbicide resistant weeds.
- The development of sustainable weed management strategies for the newly adopted herbicide tolerant crops to stop the potential emergence of ‘super weeds’ such as, for example herbicide-resistant weedy rice.
- An understanding of the impact of climate change on weeds (such as the ‘C_3’ weeds) and the further development of their management strategies.
- The development and use of computer-based expert systems for the identification and solving of complex weed management problems.
- The development of new physical methods of weed management including precision agriculture technology through greater use of guidance systems, GIS, GPS and remote sensing technology.

- The development of new biological management options including the use of suppressive crops and forage plants, natural products, and classical biological control methods for emerging weed problems.
- The development of site specific weed management options, using expert systems to identify and map problem weeds and to minimising herbicide use.
- An understanding of the mechanisms, then the prevention, of the expansion of invasive alien species, due to increased international trade, transport and tourism.
- The development of effective technology transfer pathways to end users for a faster uptake of improved management options.
- Education of the next generation of weed scientists for the Asian-Pacific region.

The earlier sections of this paper focused on the four main problems facing agriculturalists, land managers and researchers today, now I provide a brief inventory of some of the approaches that may be of use in meeting these challenges in the future.

Biotechnology in Weed Science:

The growing of transgenic crops remains controversial in some parts of the world; however, by 2015, there were 180 million ha of transgenic crops being grown in 28 countries (James, 2015). In the case of transgenic herbicide tolerant crops, a single, non-selective herbicide application can be used to control all the weeds within the crop and so herbicide tolerant crops have the potential to significantly increase food quality, to provide for an approximate 20% reduction in the use of herbicides and for the wider use of no-till agricultural systems which may help in soil moisture and nutrient conservation.

A concern in planting herbicide tolerant crops and their management with a single herbicide is the risk of selecting weed plants that are resistant to the herbicide concerned. Therefore, for each herbicide tolerant crop grown there needs to be a management plan developed, which acts as a safeguard to help prevent the overall risk of herbicide resistance developing from the overuse of a single mode-of-action herbicide.

Within the Asian-Pacific region, eight countries (India, China, Myanmar, Philippines, Australia, Bangladesh, Vietnam and Pakistan) are currently growing transgenic crops over 20.1 million ha, which represents 11.2% of the world production of such crops. Of these countries India has 11.6 million ha under cotton; China 3.7 million ha under cotton, tomatoes, papaya and capsicum; and Pakistan has 2.9 million ha under cotton. While in Australia (0.7 million ha) glyphosate tolerant cotton varieties have been grown for some years, and more recently glyphosate tolerant canola and glufosinate tolerant cotton crops have become available.

Beyond the development of crops tolerant to herbicides, biotechnological approaches may help develop weed management in other ways including; 1) in the identification of weed species from morphologically similar crops and native plants, 2) the determination of the origin of a new weed invasion and its genetic similarity to populations of the same weed in other parts of the world, 3) in the detection of herbicide-resistant weeds in the field and 4) in the modification of biological control agents to allow for improved virulence or better weed consumption in the field.

Computing technology:

The recent developments in computing technology has made many kinds of modelling approach available to the weed scientist, and this will help in the more rapid development of efficient and environmentally sound weed management practices. A number of commercially produced computer programs and simulation models are now available to help identify weed species, to predict the outcomes of weed-crop interactions and weed seed bank dynamics, to determine the distribution, abundance and spread of weeds, to predict the rate of evolution of herbicide resistance, as well as the fate of herbicides in the environment.

The computing technology may impact upon weed management in the Asian-Pacific region in the future. For e.g., the climate matching software, CLIMEX is an important tool for the exploration of the effects of climate on the distribution of an invading weed. The software allows for the simultaneous matching of the native range of a weed to that of a potential new home (Sutherst *et al*., 2007).

Weed identification can be improved using the software system LucID. LucID keys have been developed for a range of weed flora within the southern part of the Asian-Pacific region and offer benefits over traditional keys including ease of use and improved accuracy, since weed characteristics can be analysed in any order convenient to the user. Population dynamics models can also be used to investigate the evolution of traits in weed populations. In particular, models of the evolution of herbicide resistance (Thornby *et al.,* 2009) have been useful in analysing how management practices and weed characteristics contribute to the speed of evolution of resistance to herbicides in specific weed cases, and in specific cropping systems.

One such tool is the Weed Seed Wizard, which is a computer simulation tool that uses location-specific management inputs and site-specific weather data to predict and monitor changes in weed seed banks in arable land and estimates the losses in crop yield caused by the emergence of weed populations from the seed bank. The tool helps inform a land manager of the best weed management choices available to obtain the best management of a number of weed and to manage herbicide resistance.

New approaches to weed management:

Reduction in herbicide use: For various reasons, notably those of herbicide resistance and the growing public demand for organically grown produce, there has been a push for land managers to use less herbicide in their weed management practices. To achieve reductions in herbicide use, a number of options could be developed in the place of synthetic herbicide use; 1) biological control including the use of bio-herbicides, living mulches and ground covers, 2) the use of suppressive (competitive and/or allelopathic) crop or pasture plants, and 3) physical and chemical weed control delivered in the form of precision tillage and chemical spray application technology.

New natural herbicides: Significant amounts of work have been undertaken in the Asian-Pacific region to develop a new class of natural herbicides. Allelochemicals are secondary plant metabolites produced by plants (many of which are weeds) that are released into the environment as exudates from their roots or washings from their leaves, or in the course of time, from their litter. Once in the environment, such chemicals can inhibit the growth of neighbouring plants and can be active at very low concentrations. However, their use as natural herbicides has several limitations, including their poor or non-selectivity, and their rapid breakdown once in the soil. Their multi-site action would help prevent the evolution of herbicide resistance in target plants, and they would have value in organic farming systems.

Weed risk assessments: Certain countries around the world employ legislation that restricts the entry of certain plant species. This approach would reduce the number of new, potentially damaging weeds into those country. In Australia plant material for importation and of all kinds is assessed before arrival or at the point of entry (Downey *et al.*, 2010) by a weed risk assessment system. This system is a decision support system to assess the potential of these plants to become weeds. The use of this, or a similar system, needs to take hold in all Asian-Pacific countries.

Nanotechnology: Nanotechnology has the potential to deliver herbicides to weeds in an eco-friendly way, without leaving any toxic residues in the soil and environment. In addition, less herbicide will be needed when the active ingredient is delivered using nano-particles, which are typically less than 100 nm in size. Nano-particles encapsulating the herbicide can be delivered directly to weeds as a spray application; or they can be expected to blend with soil particles and prevent the growth of weeds that may have become resistant to conventional herbicides (Ali *et al.*, 2014).

Conclusions

As identified by Rahman *et al*. (2012), the Asian-Pacific Weed Science Society has played an extremely important role in connecting a very large number of weed scientists, from a large number of countries, over a large number of years, by providing a vibrant forum for the exchange of weed science information and ideas. However, we are now entering a period of unprecedented population growth, one of rapid climate change and the speedy appearance of new significant weeds, and where the growing demand for agricultural products must be balanced with the need for biodiversity conservation.

The Society must rise to these new challenges and assist further in the immediate years, by 1) promoting the use of study groups to focus in on the key threats to food and land protection in our region such as those of weedy rice, herbicide resistance and new invasive weed introductions, 2) by the organising of regional workshops on these key threats then, 3) by supporting the publication of the findings of these workshops within special issues of our national and regional weed science journals, 4) by encouragement of the younger scientists to seek higher degree education in weed science and related topics, and 5) being a voice in the identification of new emerging issues of weeds and creating long-term solutions to these new weed problems.

As identified by Rahman *et al.* (2012) the Society must take on an active role in making the public aware of the weed factors that will endanger our food production and land protection systems and identify the ways in which these threats can be mitigated.

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Commemorating 50 years of the Asian-Pacific Weed Science Society (1967-2017)

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Abstract

The Asian-Pacific Weed Science Society (APWSS) was founded on June 22, 1967, during the First Weed Control Inter-change ,held in Hawaii, USA, through the vision, planning and hard work of three founding fathers: Roman Romanowski, William Furtick and Donald Plucknett. The Society was formed with the primary objective of promoting Weed Science, particularly in the Asian and Pacific regions, by pooling and exchanging information on all aspects of Weed research and weed control.

The Society's activities include holding of conferences every two years, organizing and sponsoring symposia, workshops and training courses in Weed Science, publishing the proceedings of those conferences, symposia, and workshops, a newsletter, books and other special publications about weeds and their control in tropical agriculture. The APWSS has about 300-400 members, and is affiliated with 18 national Weed Science Societies in the Asian-Pacific region. APWSS has played a highly significant role in bringing together the scientists, researchers, extension, and industry workers in Weed Science in the region and providing a forum for exchange of weed-related information. This exchange and collaboration is extremely important in finding solutions and strategies to manage weeds that continually challenge farmers and agricultural workers in their objective of obtaining high crop yields.

This paper was written to commemorate the 50th anniversary year of APWSS to reflect on the activities and achievements for the past 50 years and to provide us with the insight, past experiences and lessons learned to help us move into the future and set the directions of the Society for the next 50 years.

How APWSS began: the need to establish linkages

The founding years: 1967-1969

The beginnings of APWSS would have been sometime in 1965 to 1967, when three professors, Dr. William Furtick of Oregon State University (OSU), Dr. Roman Romanowski Jr., and Dr. Donald Plucknett, both of the University of Hawaii (UH), began an OSU-UH international collaborative program on weed control to screen new herbicides under subtropical conditions in Hawaii. In January 1967, during one of their Annual OSU-UH Herbicide Screening Trials, the three of them decided to go apart from the crowd, and meet in a kitchen of the East Kauai Methodist Church and began to brainstorm and make plans to expand the collaboration to the Asia-Pacific region. Their initial plans were to get a small group of scientists, researchers, extension workers to meet and find out mainly who are the weed workers in the Asia-Pacific, what are the major weeds and weed problems, and what linkages are necessary to promote Weed Science research and development in the various countries in the region. Out of this need to establish linkages, the first "Asian-Pacific Weed Control Interchange" was held on June 16-22, 1967 at the University of Hawaii in Honolulu during the first week; and then, in the island of Kauai during the second week. The

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meeting was attended by 87 delegates from 22 countries and was sponsored by the East-West Center for Technical Interchange and the University of Hawaii. On the last day of the Interchange, the delegates met at the Prince Kuhio Hotel on the island of Kauai, organized the Asian-Pacific Weed Science Society and elected its first set of officers, Dr. Marcos R. Vega as President and Dr. Roman Romanowski as Secretary. Dr. Donald Plucknett served as APWSS General Secretary for 14 years, from 1969 to 1981.

Thanks to the support of the East-West Center during its early years and the outstanding leadership from an energized, committed membership and individuals who built well beyond the vision, enthusiasm and hard work that our founding fathers started in that little church in Kauai, the APWSS has now grown into a major regional and truly international weed science society (*From a letter written by Dr. Donald Plucknett, one of the founding fathers, published in APWSS: Commemorating 40 years in 2007).*

Objectives of the Society

Promote weed science in Asia-Pacific region, pool and exchange information

The objectives of the Society were established as "to promote weed science, in particular, in the Asian and Pacific regions, by pooling and exchanging information on all aspects of weed science" During the first Conference in 1967, the initial objectives were also to identify the weed workers in the Asian-Pacific area, what are the major weeds and weed problems, what are the research and development needs of the various countries, and what linkages are necessary or possible in dealing with the perceived needs.

The first meeting, described by Dr. Plucknett as a real joy, brought together many weed workers who have been working in isolation for the first time, meeting others with similar interests. Probably, more important was the fact that formation of APWSS brought into focus weed control research, then mostly confined to temperate countries, to tropical countries in Asia and the Pacific. Since that first conference in 1967, APWSS has now held 25 conferences, once every two years, over the past 50 years and will be holding its 26th Conference during its 50th anniversary, at Kyoto, Japan, in 2017. Details and highlights of these APWSS Conferences up to the end of the first 40 years of existence have been described in a 40th year commemorative publication (Baltazar, 2007). This paper will summarize the high points of these Conferences and highlights the activities and achievements of the Society since its formation in 1967.

Activities and Achievements

Biennial Conferences - *Work together to solve problems that seem insoluble*

Since 1967, APWSS has held 25 Conferences every two years in different countries and hosted by the respective Weed Science societies and various government and educational institutions (Table 1). These gatherings have since become major fore by which research results are shared, information disseminated to agricultural researchers and linkages developed from the fellowships that resulted from these collaborations. Through the Conferences, APWSS has played a key role in the rapid institutionalization of weed management as a science in many universities and research centers. In the words of one of its founding fathers, Dr. Donald Plucknett: "*…APWSS has linked many scientists in disparate places and enabled them to form relationships, correspondence, and collaborative linkages that flourished through the years. Meeting key people and finding ways to work together on large problems that seem insoluble have been a key feature of APWSS and its success…*"

Table 1: List of APWSS Conferences held for the past 50 years, from 1967 to 2017

Conf. No.	Date	Venue	Papers presented (No.)	Delegates (No.)	Countries participating (No.)
The Founding Years					
1st	June 12-22, 1967	Honolulu, Hawaii, USA	50	87	22
2nd	June 16-20, 1969	Laguna, Philippines	47	146	20
The Formative Years					
3rd	June 7-12, 1971	Kuala Lumpur, Malaysia	74	200	20
4th	March 12-16, 1973	Rotorua, New Zealand	78	300	18
5th	Oct 5-11, 1975	Tokyo, Japan	114	308	21
6th	July 11-17, 1977	Jakarta, Indonesia	105	314	22
7th	Nov 26-30, 1979	Sydney, Australia	134	311	18
The Growing Years					
8th	Nov 22-29, 1981	Bangalore, India	120	311	18
9th	Nov 28-Dec 2, 1983	Manila, Philippines	83	305	20
10th	Nov 24-30, 1985	Chiang Mai, Thailand	117	530	23
11th	Nov 29-Dec 5, 1987	Taipei, Taiwan, China	144	462	17
12th	Aug 21-16, 1989	Seoul, South Korea	198	589	21
The Maturing Years					
13th	Oct 15-18, 1991	Jakarta, Indonesia	96	199	16
14th	Sept 6-10, 1993	Brisbane, Australia	114	453	18
15th	July 24-28, 1995	Tsukuba, Japan	182	450	20
16th	Sept 8-12, 1997	Kuala Lumpur, Malaysia	140	375	27
17th	Nov 22-27, 1999	Bangkok, Thailand	223	392	21
The New Millennium Years					
18th	May 28-Jun 2, 2001	Beijing, China	201	400	26
19th	March 16-21, 2003	Manila, Philippines	143	200	20
20th	Nov 7-11, 2005	Ho Chi Minh City, Vietnam	111	258	23
21st	Oct 2-6, 2007	Colombo, Sri Lanka	134	189	19
The Challenging Years					
22nd	March 8-12, 2010	Lahore, Pakistan	112	160	9
23rd	Sept 26-29, 2011	Sebel, Cairns, Australia	140	210	26
24th	Oct 22-25, 2013	Bandung, Indonesia	169	116	15
25th	Oct 13-16, 2015	Hyderabad, India	805	600+	20+
26th	Sept 18-22, 2017	Kyoto, Japan			

The following is a brief summary of highlights of the history of APWSS Conferences:

- Two Conferences were held in the latter half of the 1960s, the founding years of the Society.
- Five Conferences were held in each of the five decades, from 1970s, (the Formative Years), through the 1980s (The Growing Years), and through the 1990s (The Maturing Years).
- There were four Conferences each held in the 2000s (New Millennium years) and the next decade (The Challenging Years), including the 22nd Conference at Lahore. The 2009 APWSS Conference was delayed and held one year later, in 2010, due to security difficulties in Pakistan, at that time. The 5th Conference for the current decade is being held in Kyoto, Japan in September 2017.
- The number of delegates who attended the Conferences has increased from 87 founding members in 1967 to an average of 300 members until the mid-2000s, with membership peaking to 589 in 1989.
- Membership and delegate participation decreased to an average of 200 starting the latter part of the 2000s. The number of papers also increased from 50 in 1967, peaking at 600+ in 2015, with an average of about 150 papers presented each year.
- The number of participant countries was lowest in 2010 (only 9) and was highest in 1997 (27) with an average of 21 countries for each year, with some participants coming from countries outside the Asian-Pacific region.
- Among the host countries, the Conferences were held three times each in the Philippines (1969. 1983, 2003), Japan (1975, 1995, and 2017), Indonesia (1977, 1991, and 2013) and Australia (1979, 1993, and 2011). It was held two times each in Malaysia (1971, 1997), India (1981, 2015), Thailand (1985, 1999), and China (1987, 2001). It was held once each in the USA (1967), New Zealand (1973), South Korea (1989), Vietnam (2005), Sri Lanka (2007), and Pakistan (2010).

Publications

Books

"The World's Worst Weeds" and "A Geographical Atlas of World Weeds"

In answer to one of the APWSS objectives of determining what are the weeds and weed problems in the Asia-Pacific region, writing of two famous books, "*The World's Worst Weeds*" and "*A Geographical Atlas of World Weeds*" was planned and started during the 1969 Conference. These books were co-authored by APWSS founding members Drs. Leroy Holm, Juan Pancho, Donald Plucknett, and James Herberger. Both books were written at the East-West Center with support from APWSS and the East-West Center at the University of Hawaii. The *World's Worst Weeds* was published in 1977; and *A Geographical Atlas of World Weeds* was published in 1979, during the early, formative years of the Society.

As Dr. Leroy Holm, the senior author, said in his presentation during the 1969 Conference, "*I have worked on a weed problem, which has reached emergency proportions in one country in Asia, in that locality there was not even the means for giving scientific, common, or local names to the species… Of 300, 000 angiosperms, 30,000 may behave as weed, we are looking at 3,000 and were able to reduce the list to 100…. We need to know what the world's worst weeds are – so that we can do first things first*".

Conference, Symposium, or Workshop Proceedings and Journals

Twenty-five volumes of the APWSS Conference proceedings have been published, with some Conferences producing two large volumes. The proceedings contain the papers and posters presented during the Conferences, including papers presented in special symposia or workshops which may have been held in conjunction with a particular conference. The quality of the Proceedings has improved substantially over the years. Most of the volumes are now digitized and available at the APWSS website.

The international Journal - *Weed Biology and Management*, is published by the Weed Science Society of Japan, with encouragement and contributions from APWSS members and the various national weed science societies affiliated with APWSS. First published in March 2001 with Dr. K. Kobayashi as the first Editor, it is now on its 11th year and includes full papers and short reports of results of original research, and reviews.

Newsletters and other special publications

The APWSS Newsletters keep the members informed of the Society's various activities, as well as facilitate communications among members and among the national Weed Science societies affiliated with APWSS. The first APWSS Newsletter was published in 1973 with Philip Motooka as the first Newsletter Editor, from 1973 to 1983; followed by Beatriz Mercado, from 1983 to 1987; Aurora Baltazar, from 1987 to 1993 and 1997 to 2001; John Swarbrick, from 1993 to 1997; Yasuhiro Yogo from 2001 to 2005. An average of 4 to 5 issues have been published biennially (up to 7 issues, during 1977 to 1979) from 1973 to 2005.

There was a 3-year period (2005 to 2008) when there was no Editor and no Newsletter was published. In 2008, Nimal Chandrasena (Australia), took over the role of Newsletter Editor, resurrecting the publication of the Newsletter and produced up to three Newsletters per year for several years. Asad Shabbir (Pakistan) took over in 2012 after being appointed as Assistant Newsletter Editor at the 23rd APWSS, at Cairns, Australia, in 2011.

At the 2015 Hyderabad 25th APWSS, Bhagirath Chauhan (Australia) was given the responsibility. The Newsletter includes news items from the member countries, activities of members, developments in the industry, news on appearance of new weed species and other problem weeds, and new trends and developments in weed science research, teaching and extension in the region.

To mark the 10th year anniversary of APWSS in 1977, a 46-page publication "Commemorating 10 years of APWSS "*….was compiled, designed and published in July 1977…*" by the International Plant Protection Center (IPPC) at the Oregon State University in Corvallis, Oregon, USA (APWSS, 1977). Then, in 2007, to mark its 40th year anniversary, a 52-page publication "Commemorating Forty Years of APWSS" was compiled and written by Aurora Baltazar and published in October, 2007 (Baltazar, 2007).

The 40th Anniversary publication included details of each conference (i.e. numbers of participants, papers presented, list of officers, speakers, organizers, awardees, notable activities, and other milestones or highlights). Excerpts from papers and speeches delivered, which may have shaped or reflected the major developments of Weed Science in the region were also included for each conference.

At the 25th APWSS 'Silver Jubilee' Conference held at Hyderabad, in 2015, an important book entitled "*Weed Science in the Asian-Pacific Region*" was published sponsored by APWSS and the Indian Society of Weed Science (ISWS). The book features chapters on the status of Weed Science research, extension, and education in many countries in the Asian-Pacific region and was edited by a team of weed scientists that comprised V. S. Rao, N. T. Yaduraju, N. R. Chandrasena, Gul Hassan and A. R. Sharma (see Rao *et al*., 2015).

Symposia, Workshops, Training Courses/Seminars, Working Groups

APWSS has sponsored and held the following symposia and workshops in various countries of the Asian-Pacific region. These gatherings were held either separately, or in conjunction with a particular APWSS Conference. Some of the well-known examples include the following:

- Symposium on "*Integrated Control of Weeds*" was organized and held in 1975 in conjunction with the 5th APWSS Conference held in Tokyo, Japan.
- An APWSS-sponsored FAO/IWSS Expert Consultation on Improving Weed Management in Developing Countries Workshop was held in Rome, Italy in September 6-11, 1982. A FAO Panel of Experts for Weed Science was appointed and most of them were IWSS and/or APWSS members.
- An international symposium on "*Innovative Weed Management Strategy for Sustainable Agriculture*" was held in conjunction with the 15th APWSS conference held in Tsukuba, Japan in 1995. It was sponsored by APWSS, the Japan International Research Center for Agricultural Sciences (JIRCAS) and the Food and Fertilizer Technology Center for the Asian-Pacific Region (FFTC). The papers presented during the Symposium were published in proceedings in June 1996.
- Two International Training Courses on "*Weed Science in the Asian Tropics*" were held in 1996 and 1997 in Kasetsart University, Thailand as a post-1995 APWSS conference activity. These were sponsored by APWSS and the Weed Science Society of Japan. Fifteen trainees attended the 4-week training course.
- The 15th APWSS Conference Organizing Committee, the Weed Science Society of Japan and the Korean Society of Weed Science co-sponsored an International Seminar on "*Weed Management in the North Asian region (Japan, Korea, China)*", which was organized by the Northeast Agricultural University. It was held in Harbin, China on August 20-23, 1996 and chaired by Professor Su Shao Quan of Beijing, China. Papers presented during this Symposium were published into a Proceedings of the Northeast Asian Area Weed Science Symposium of China, Korea and Japan.
- APWSS, in collaboration with the Cuu Long Delta Rice Research Institute organized and sponsored the "*International Symposium on Wild and Weedy Rices in Agro-ecosystems*", which was held at Ho Chi Minh City, Vietnam in August 10-11, 1998.
- The papers presented during this symposium were published in the IRRI Proceedings Series entitled "*Wild and Weedy Rice in Rice Ecosystems in Asia – A Review*" under the collaborative partnership among the APWSS, the Cuu Long Delta Rice Research Institute and IRRI. It was published in 2000 and edited by Duong Van Chin, Baki Bakar, and Martin Mortimer.
- The Asian-Pacific Herbicide Resistance Working Group (APHRWG) was formed in 2001 and chaired by Dr. Kayuzuki Itoh. Its main objective is on herbicide resistance management and search for solutions to herbicide-resistant weed problems in the Asia-Pacific region.

- A satellite workshop of the 18th APWSS conference on "*Control of Echinochloa species*" was held on May 27, 2001 sponsored by FAO and APWSS in Beijing, China. Twelve papers were presented on various aspects of biology, ecology and management of barnyard grass and published in a proceedings entitled "*Echinochloa Control in Rice*" in 2003 and edited by Kil-Ung Kim and Ricardo Labrada.
- Another FAO-APWSS collaboration sponsored a pre-conference workshop on "*Control of Cyperaceae Weeds*" was held during the 20thAPWSS Conference at Ho Chi Minh City, Vietnam on 6 November, 2005. Twelve papers were presented and about 20 weed scientists from south, south-east, and East Asia discussed current issues on control of Cyperaceae weeds, some of which had emerged as major weed problems. The proceedings were published in 2006 in a book entitled "*Management of Sedge Weeds in Rice*" and edited by Kil Ung Kim and Ricardo Labrada.
- Five satellite symposia were held at the 25th APWSS Conference held at Hyderabad, India in 2015. These were "*Weed Management in Conservation Agriculture*"; "*The Weedy Rice Challenge in Asia*"; *Herbicide Resistance: Current Status and Future Challenges Globally*"; "*Biological Control – Progress and Future Prospects in Asia-Pacific Region*", and "*Utilization of Weeds as Bio-resources*". The plenary and invited papers were published in Volume 1 of proceedings edited by A. N. Rao and N. T. Yaduraju (Rao and Yaduraju, 2015).

Best Paper Awards, Travel Grants, Honorary Members

Best Paper and Best Poster Awards

For 20 years, from 1983 to 2003, APWSS, in cooperation with the Monsanto Chemical Company, established the Best Paper (oral) and Best Poster Awards, to recognize and encourage high quality research in weed science in the Asian-Pacific region. During each conference, three winners (first, second, and third place) of each category were chosen from all the papers and posters presented, based on a set of criteria formed by the APWSS Best Paper/Poster Award Committee. The winners were announced during the banquet and closing ceremonies held on the last day of the conference. The award included a plaque and a cash prize.

Young and Deserving Scientists Travel Grant

The Young and Deserving Scientists Travel Grant was initiated in 1987; however, rules and criteria concerning selection of grantees were finalized only in 1993 and implementation started in 1995. The travel grant provides for partial, financial support to young and deserving weed scientists, enabling them to attend and present a paper at the Conference. The criteria were: 1) grantees should not be more than 35 years of age, and 2) grantee must present a high quality paper at the Conference. Each recipient is given $500 and exemption from the registration fee. The panel to select qualified recipients is composed by the Local Organizing Committee and typically, include senior APWSS members. Each year, since 1995, two or three young and deserving recipients have been selected in this manner and rewarded accordingly.

Honorary Members

Members who have given outstanding service to the Society may be elected as an honorary member at any of the Annual General Meetings held during a Conference. The first honorary member, Y. Baron Goto was elected in 1973 at the 4th Conference. This was followed by the election of Kenji Noda, Shooichi Matsunaka and Les Matthews (1975), Marcos Vega (1977) and Mohamad Soerjani (1981, 2013). At the 20th anniversary of APWSS in 1989, a special program was held to honour the founding members, charter members, and past presidents for their contribution to the Society. A Special Citation was presented to Donald Plucknett, one of the three founding fathers of APWSS, for his pioneering and dedicated efforts in establishing the Society.

Affiliations and Collaborations with other Weed Science Societies

Any national or regional Weed Science Society which actively participates in APWSS activities is considered an affiliate of APWSS (see Table 2). The Presidents of each society are included as members of the APWSS Executive Committee and attend the Executive Committee meetings, which are held during each Conference. The affiliated Societies take turns in hosting and organizing the APWSS Conferences.

The Weed Science Society of Indonesia was the first national society to become affiliated with APWSS, in 1971. By 1973, the national weed science societies of USA, Japan, India, New Zealand and Australia became affiliated with APWSS. By 1989, there were 13 national societies represented during the Executive Committee meeting of the 12th conference from the following countries: Australia, China, India, Indonesia, Japan, Korea, Malaysia, New Zealand, Pakistan, Philippines, Taiwan, Thailand, and USA. Joining the list in the 1990s decade were: the Weed Science Society of Vietnam in 1997; the Plant Protection Society of Sri Lanka in 1999 (this was previous named the Weed Science Society of Sri Lanka, WSSSL, and was amalgamated) and the Weed Science Society of Bangladesh in 2008, and the Weed Science Society of Israel and Iranian Weed Science Society in 2015.

Table 2: National Weed Science Societies affiliated with APWSS

Name of Society	Country	Year Founded	Year of Affiliation
Council of Australian Weed Societies	Australia	1976	1973
Weed Science Society of America	USA	1956	1973
Weed Science Society of Bangladesh	Bangladesh	2008	2008
Weed Science Society of China	China	1981	1989
Indian Society of Weed Science	India	1968	1973
Weed Science Society of Indonesia	Indonesia	1971	1971
Weed Science Society of Japan	Japan	1962	1973
Korean Society of Weed Science	South Korea	1981	1989
Malaysian Plant Protection Society	Malaysia	1976	1989
New Zealand Plant Protection Society	New Zealand	1948	1973
Pakistan Weed Science Society	Pakistan	1987	1989
Weed Science Society of the Philippines	Philippines	1968	1989
Weed Science Society of the Republic of China	China (Taiwan)	1980	1989
Weed Science Society of Thailand	Thailand	1971	1989
Weed Science Society of Israel	Israel	1964	2015
Weed Science Society of Vietnam	Vietnam	1997	1997
Weed Science Society of Sri Lanka	Sri Lanka	1990	1999
Iranian Society of Weed Science	Iran	1950	2015

- APWSS became an affiliate of the International Weed Science Society (IWSS) in 1975. The first set of officers for IWSS was installed during the 1977 business meeting of APWSS in Indonesia. Les Matthews (New Zealand) was appointed the first IWSS President; and Shooichi Matsunaka (Japan) was the first appointed APWSS representative to IWSS.
- In the 1970s, the weed specialist post at the FAO Plant Protection Service was held for short periods by Leroy Holm and Colin Little. When it developed as a permanent position in 1977, it was initially held for several years by L. J. Matthews. Ricardo Labrada occupied this position from the 1990s to 2000s.
- In 1987, APWSS and the Weed Science Society of America (WSSA) established an official exchange of Conference delegates to promote closer contact between the two societies. The first official WSSA delegate and WSSA Liaison to APWSS was Richard Schumacher and the first APWSS delegate to WSSA was Yuh-Lin Chen, then the APWSS president for 1985-1987.
- Other APWSS activities conducted in collaboration with other Societies included a logo design contest wherein the current APWSS logo (globe design), designed by A. N. Rao of IRRI, Los Banos, Laguna, Philippines was selected as the winner.
- In 1989, the Korean Society of Weed Science, hosting the 12th Conference, donated the APWSS flag. The flag is passed on at the close of each conference to symbolize the passing of responsibility from the current host society to the next.

APWSS and 'World's Worst Weeds'

During its formative years, one of the objectives of APWSS was to identify what the weeds are and the major problems they cause in tropical crops. With the publication of the book "*World's Worst Weeds*" by Holm *et al* in 1977, about 100 species were identified as the worst weeds in the world and most of these weeds were recognized as originating in the tropics. Purple Nutsedge (*Cyperus rotundus* L.), a species native to Asia, was named the World's Worst Weed, because it was found or reported in the most number of countries and infested the most number of crops. Another focus during the formative years of APWSS was to promote Weed Science research, then mostly confined to temperate regions, in the tropics where most, if not all of the World's Worst Weeds were found, and how to control or manage these weeds, as they were the main constraints to obtaining high yields in agricultural crops.

The papers presented at the APWSS conferences through the years reflected the shifts in pest/weed paradigms and weed management strategies that have been developed over the years in the Asia-Pacific region as well as in other parts of the world. These included predominant weed control methods, mostly cultural, mechanical, and chemical control methods during the early formative to growing years, (1960s to 1980s) to ecological, biological, and biotechnical approaches during the maturing and new millennium years (1990s to 2010s).

While purple nutsedge (*Cyperus rotundus*) has been considered the world's worst weeds in upland crops, barnyard grass (*Echinochloa crusgalli*) is considered the 'worst weed' in rice-growing areas. When the evolution of weed resistance to herbicides appeared in east and south-east Asia and Australia in the 1980s, barnyard grass was among the first weeds reported to have evolved resistance to herbicides.

With increased use of herbicides having different modes of action, the number of multiple resistant weeds in rice have also grown, led by the Superweeds *E. crusgalli*, *Lolium rigidum*, *Phalaris minor*, *Sagittaria montevidensis*, *S. pygmea*, *Lindernia dubia*, *Cyperus difformis*, and *Scirpus juncoides*. Other super weeds include weedy rice and the invasive weed – Parthenium (*Parthenium hysterophorus* L.). Interestingly, reports of purple nutsedge evolving resistance to herbicides are yet to be found.

APWSS and Future Challenges

Developing Management Strategies for Multiple-Resistant Weeds

Without doubt, APWSS has achieved its other key objective of bringing together weed scientists working in research, industry, education, extension and similar fields by providing a vibrant forum for exchange of Weed Science information and collaboration in helping solve the many big and small problems caused by weeds in tropical, sub-tropical and temperate agriculture in the region. Among the major challenges, which APWSS can help solve are determining the factors affecting evolution of herbicide resistance; what makes a particular weed species more resistant (or more multiple-resistant) than other weeds.

An increase in studies on eco-evolutionary concepts of weed management and developing closer research relationships with evolutionary biologists may assist in understanding the evolution of traits that allow weeds to adapt to agricultural interventions to enable weed scientists to determine IWM strategies that prevent evolution of resistance (Baucom and Holt, 2009; Neve, *et al.*, 2014; Delye, *et al.*, 2013; Menalled, *et al.*, 2016). Additionally, we should help in dissemination and development of new non-chemical control methods, such as robotic weed control and ecological approaches to reduce the weed seed bank.

APWSS should continue to sponsor workshops, training courses, and similar activities and support publishing of special issues of the journal *Weed Biology and Management* or similar publications. Most of all, APWSS should continue to be at the forefront in helping promote and develop Weed Science in the region and continue what has been started by our founding fathers 50 years ago in that "tiny, little rural church kitchen in Kauai" for the next 50 years.

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Temperature and soil moisture as principal factors on emergence and growth of weeds in rice production in Asian-Pacific Region

Hirohiko Morita[32]

Abstract

Further development of effective weed management technologies is still a major goal in rice production, particularly in direct-seeded fields and rain-fed rice, distributed in the temperate and the tropical, sub-tropical regions, in Asian-Pacific region. The emergence and the early growth of weeds are affected by meteorological factors in different ways. Effects of two of the most important factors, temperature in the temperate region, and soil moisture in the tropical and sub-tropical regions, are summarized.

As examples of these relationships, an analysis of the effects of temperature on the leaf emergence of *Echinochloa* species – a major group of rice weeds in the temperate region - is presented, in order to predict the specific leaf-stage of the weed, which indicates the end of proper application time of herbicides in direct-seeded rice fields in Japan; along with a review of the effect of soil moisture rate on the emergence of weeds from rain-fed rice fields of tropical regions. Promoting the analysis of such factors is important to further support for the development of effective and labour-saving weed management technologies, including the use of herbicides in rice production.

Introduction

Rice (*Oryza sativa*) is one of the most important crop in the world harvested in 162.7 million ha with 741.5 million tons as paddy in 117 countries and areas of the world in 2014, according to FAOSTAT 2017. When these 117 countries and areas are classified depending on the latitude of their capital into 15 degree intervals from the equator, the temperate regions of 30 to 45 degree latitude have 22.4% of harvested areas and 33.3% of production with yield of 6.8 ton/ha, while the areas of 0 to 15 degree latitude and of 15 to 30 degree latitude, approximately belonging to the tropical and the subtropical regions, have 29.4%, 24.4% with 3.8 ton/ha and 48.0%, 42.0% with 4.0 ton/ha, respectively in cultivated areas, production and yield. Considering the differences in yield between tropical and temperate countries and areas, different strategies are necessary to increase the rice yield for these regions, including further development in weed management technology.

Among meteorological factors, temperature and soil moisture condition have been described as principal factors affecting emergence and growth of weeds, along with other factors such as soil pH, soil fertility, oxygen, sunlight and so on (King, 1966, Ueki and Matsunaka, 1972, Ito, 1993). However, the importance of temperature and soil moisture is quite different between the temperate and the tropical regions (Figure 1), particularly at the beginning of the rice cultivation season. In temperate regions such as Japan, Korea and central to northern China, temperature at the beginning of rice cultivation is lower than in the tropics.

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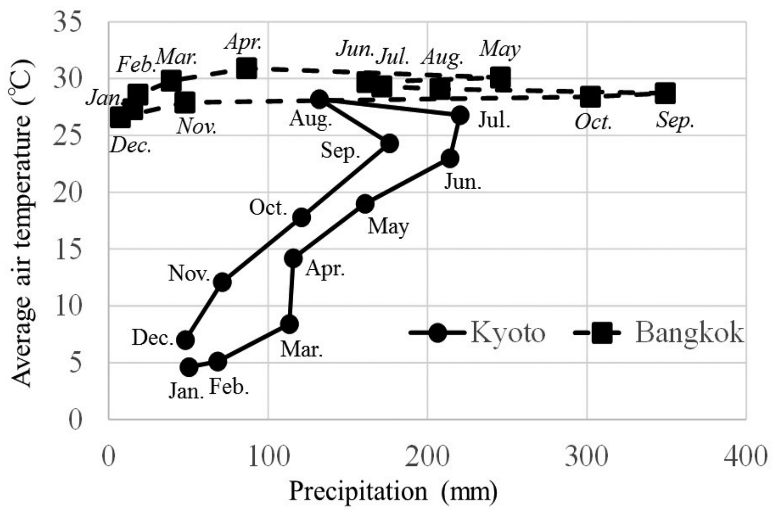

Fig. 1 Climograph at Kyoto, japan in temperate region and at Bangkok, Thailand in tropical monsoon region (compiled from "Chronological Scientific Tables 2012 by National Astronomical Observatory of Japan").

As a consequence, low temperature affects the safety and efficacy of selective herbicides conspicuously through the growth of weeds and rice seedlings. In order to avoid phytotoxicity to the establishing juvenile rice plants and to control target weeds by using rice herbicides, mainly, the early-post-emergence herbicides including 'One-shot' herbicides, which are able to control weeds by a single application (Watanabe, 2011), proper application time is critical.

The proper application time, starting at the days after transplanting or the leaf-stage of rice seedlings in direct-seeded field, and ending at the particular leaf-stage of *Echinochloa* species for the most advanced individual plant in the paddy field (Morita, 2003), is explained in the herbicide use reference of pesticide registration in Japan.

Generally, the proper application time of rice herbicides is shown with more detailed descriptions in the temperate regions under lower and more fluctuating temperature than in the tropics. Spread of mechanized direct-seeded cultivation has been promoted as a labour-saving and low cost technique in rice production, while more than 97% of rice fields are mechanically transplanted in Japan. Effective weed management using herbicides is an important means to be improved further for direct-sown rice.

On the other hand, in contrast with temperate countries, in tropical regions such as south-eastern Asia, southern India, and African countries, precipitation condition is a major factor, which affects the emergence and management of weeds. This is particularly important for rain-fed rice, which is ambiguously defined as fields without receiving irrigation where soil surface is flooded by rain water received for at least part of the crop cycle. Such rain-fed rice cultivation areas are estimated to be around half of the rice cultivated area in the world (Mackill *et al*., 1996). It is clear that an analysis of the effects of soil moisture condition on weed emergence under fluctuating precipitation, particularly during the early stages of rice cultivation, starting at the beginning of rainy season, would provide information to establish more effective weed management techniques for direct-seeded rice cultivation under dry conditions in rain-fed fields.

In this paper, I provide an outline of some results of studies on the effects of temperature and soil moisture rate on the emergence and the growth of weeds, based on research conducted in Japan (as a temperate region) and, Thailand and Ghana (as tropical regions). My intention is to encourage similar research on critically-important factors as part of in our Asian-Pacific regions.

Quantifying temperature effects on the emergence and initial growth of weeds in temperate regions

A number of studies have reported the effects of temperature on germination and emergence of weed species growing in rice fields. These led to establishing, the relationships between days from sowing to emergence and daily average air- or water-temperature, based on measuring accumulated temperature for the seeds sown at different times in several lowland weeds, including *Echinochloa oryzicola* in northern Japan (Suzuki and Suto, 1975). Although the specified leaf stage of *Echinochloa* species has been used as an index showing the ending of proper application time of herbicide, it was not easy for farmers to know the correct date, when *Echinochloa* species would grow up to the specified stage from the date of puddling, transplanting or sowing in the rice cultivation (Morita, 2003).

As fluctuating air- or water-temperature affects the date to specified stage of weeds, Doi and Murakami (1977) presented the first equation to predict the growth sage of weeds, particularly, for *E. oryzicola* in transplanted rice fields of Hokkaido Prefecture, with procedures to obtain it, using accumulated temperature as the explained variable of equation. Based on their study, several authors have subsequently provided equations to predict the specified leaf stage of *Echinochloa* species, adaptable to limited areas of some Prefectures. For these equations, the accumulated temperature and the effective accumulated temperature are computed in a simple way. The daily average air temperature (T°C) and subtracted value with zero-development (T – α°C), respectively, have been used as the explained variables of the equation (Morita, 2003, 2016).

Method using weighted effective temperature, in which measured temperature in degree Celsius is transformed into the efficient equivalent, calculated from temperature-growth response was developed in order to obtain more accurate prediction of date of specified leaf-stage of the weed (Murakami *et al.,* 1990). In this method, 24 hours (one day) was divided into classes of every two degree Celsius interval according to the temperature recorded, since the efficient equivalent was given for each class of two degree Celsius. However, the procedure was too complicated to use practically. This method of the weighted effective temperature was improved to accumulate the efficient equivalent for the temperature on the each hour (Morita, 1999, 2000), which enabled to use the temperature data on each hour provided by Automated Meteorological Data Acquisition System (AMeDAS) hosted in the Meteorological Agency, Japan.

With the improved weighted effective temperature method, leaf development patterns of *E. oryzicola* and *E. crus-galli* var. *crus-galli* were analyzed for mechanically direct-seeded rice fields under wet condition in southern Akita Prefecture of northern Japan, where failures in weed management using 'One-shot' type herbicides were becoming a severe problem. Accumulated efficient equivalent necessary to estimate particular leaf-stage of *Echinochloa* from the date of final puddling was determined, based on the actual measurement of maximum leaf-stage of *E. oryzicola* and *E. crus-galli* var. *crus-galli*, respectively, in the direct-seeded farmers' paddy fields for three rice cropping seasons from 2010 to 2012, using air temperature data at four AMeDAS locations in southern Akita Prefecture.

The date to the specified leaf-stage of *Echinochloa* growth calculated with the above mentioned accumulated efficient equivalent based on AMeDAS in 2013, was closer to the date when the leaf-stage was measured actually in the direct-sown paddy fields than the date estimated by other methods such as days (ΣD), accumulated temperature (ΣT) and effective accumulated temperature in simple way (Σ (T-10))(Morita *et al.*, 2014).. By this method, the date when *Echinochloa* grew to the specified leaf-stage indicates the end of proper application time of herbicide, and this was calculated for direct-seeded rice fields in the area during the years 2010 to 2012 to compare with date of actual application recorded in farmers' management-diaries (Morita *et al.*, 2014).

It was considered that in some direct-seeded fields, the failure in controlling *Echinochloa* species, was due to the herbicides being applied later than the end of proper application time. Based on above consideration, 'One-shot' type herbicides became to be applied before the end of proper application time by farmers in southern Akita Prefecture.

Furthermore, using the improved weighted effective temperature method, the dates when maximum leaf-stage of *E. oryzicola* and *E. crus-galli* var. *crus-galli* reached to 2.0, 2.5 and 3.0, respectively, assuming the date of final paddling as 1st May, were calculated for 26 years from 1990 to 2015 based on air temperature data of AMeDAS. The results showed the degree of fluctuation in duration to the specified leaf-stage of *Echinochloa* species during 26 years, which included many types of climate conditions for direct-sown rice cultivation in southern Akita Prefecture (Figure 2, Morita, 2017).

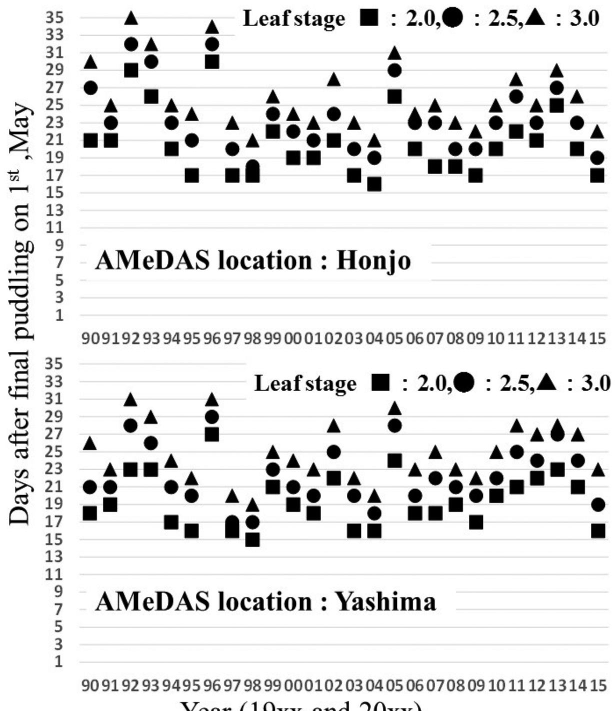

Fig. 2 Fluctuation among 26 years in days for each leaf stages of *Echinochloa oryzicola*, calculated with weighted effective temperature method, for two locations in Akita Prefecture (Morita, 2017).

Currently, accumulated values, such as day, daily average temperature and effective temperature, calculated to estimate the emergence and the leaf development of weeds, are adaptable generally only to the limited areas, such as a part of Prefecture where the data on the growth of weeds were actually collected. In order to develop methods adaptable to a wider geographical area, factors limiting these values to the particular area for which range in daily air temperature, soil temperature, quantity of solar radiation, and so on, might be candidates, should be considered. Further studies on quantifying the temperature for the emergence and the growth of weeds should be undertaken for the rational use of herbicides in rice production, particularly, in temperate regions, where low and fluctuating temperatures are important in determining the growth rates of both weeds and rice.

Analysis of soil-moisture effects on the emergence of weeds in tropical regions

In contrast with the temperate regions mentioned above, dry soil moisture conditions caused by shortage and fluctuation of the precipitation are major factors, which affect the emergence and the growth of weeds at the beginning of rice cultivation-season, especially in rain-fed rice. Rice cultivation is often extended in the tropical monsoon and savannah regions where the climate is divided into dry and rainy seasons. As a labour-saving rice production system in rain-fed fields under unstable precipitation at the beginning of rainy season when cropping would start, direct seeded rice cultivation under dry condition was recommended in north-eastern Thailand (Kabaki *et al*., 2004) and northern Ghana (Morita *et al*., 2010), respectively through research projects conducted by the Japan International Research Institute for Agricultural Sciences (JIRCAS).

In north-eastern Thailand belonging to the tropical monsoon region, emergence patterns in Cyperaceae weeds, mainly *Cyperus iria*, and rice plant (*Oryza sativa*, 'Khao Dawk Mali') from the soil of rain-fed fields were investigated under different soil moisture rates which were adjusted by putting different amount of tap water once a day.

Weed emergence was greater under soil moisture rates of 30% and 25% than under those of 20%, 15% and 10%, while rice plants emerged quicker under the rates of 30%, 25% and 20% than under those of 15% and 10%. The results suggest the possibility of obtaining the establishment of rice seedlings and avoiding the emergence of weeds through sowing rice seeds under soil moisture rate of 20% at the beginning of rainy season (Figure 3, Morita and Kabaki, 2002).

In the northern Ghana, belonging to the tropical savannah region, the emergence patterns of Gramineae, Cyperaceae and broad-leaf weeds and rice (*O. sativa*, 'Sikamo' and 'Sakai') from soils of rainfed lowland fields were determined by the similar procedures as above. The total number of emerging weeds in all three groups was conspicuously great under soil moisture rate of 20%, followed by 30%, while number of emerged weed was suppressed remarkably under soil moisture rate of 15%, throughout the soils collected from four different fields. *Paspalum scrobiculatum* L., *Acroceras zizanioides* (Kunth.) Dandy, *Digitaria longiflora* (Retz.) Pers. and *Fimbristylis* spp. were major species in Gramineae and Cyperaceae weeds, respectively.

While, rice plants could emerge more quickly under soil moisture rate of 15% as well as under that of 20%, than under 10% (Morita *et al*., 2015). The results also suggested a possibility of obtaining the establishment of rice seedlings and avoiding the emergence of weeds through sowing rice seeds at the soil moisture rate under 15% at the beginning of the rainy season (Figure 4, Morita *et al*., 2015).

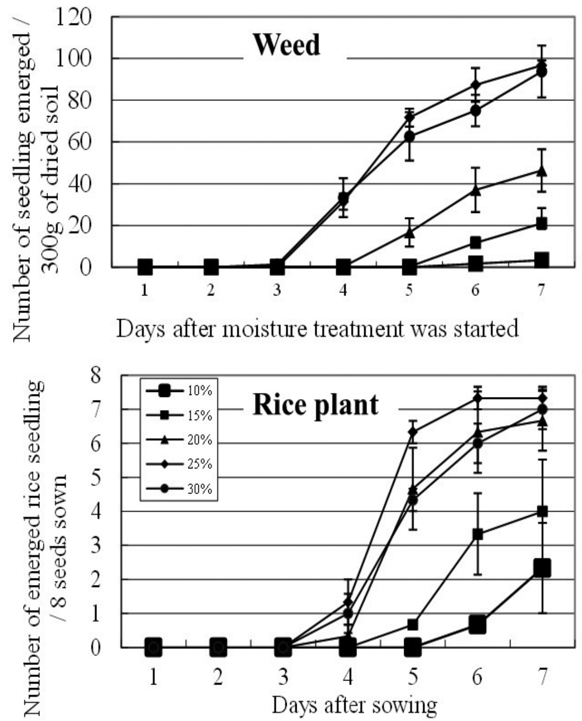

Fig. 3 Emergence patterns of weeds and rice plants under different soil moisture rates from soil of rain-fed rice field in north-eastern Thailand (Morita and Kabaki, 2002).

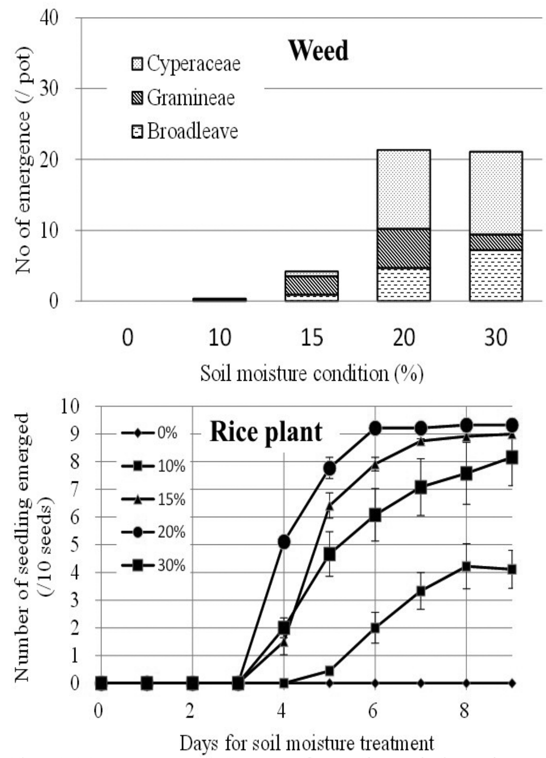

Fig. 4 Emergence patterns of weeds and rice plants under different soil moisture rates from soils of rain-fed rice field in northern Ghana (compiled from Morita *et al*., 2015).

Since above results were obtained from pot experiments, further studies on the measurement of soil moisture rates and emergence of weeds and rice plant, the changes in soil moisture with time from dry to rainy seasons and so on in actual field levels should be carried out to develop a labour –saving and rational weed management technology for the rain-fed rice fields in the monsoon or savannah regions of tropics, keeping in step of progress in the accuracy of weather forecast, particularly the precipitation forecast. Also these results would support the determination of the correct application times for the pre-emergence and the early-post-emergence herbicides in the tropical region, where rice cropping starts at the beginning of rainy season.

Conclusions

In both temperate and the tropical regions, selective herbicides, as well as non-selective herbicides, are major means for weed management in rice production regardless of irrigated or rain-fed conditions. The weed flora, specific species present in a field, their emergence pattern, weed growth stages and so on are important factors, which determine the herbicides that should be used, under different conditions.

Manipulating conditions in the field (i.e. water levels) and application time are critically important in using selective herbicides efficiently with high efficacy and without phyto-toxicity to the rice crop, particularly in the initial stages in the rice cropping season. Since the emergence pattern and the early growth are strongly affected by the meteorological conditions, such as temperature (in the temperate region) and soil moisture (in the tropical and the sub-tropical regions), biological studies on relationships between those meteorological factors and growth of weeds would contribute certainly to improved weed management technologies in rice production.

In this regard, APWSS has already played an important and an irreplaceable role in the exchange of the results and knowledge. Further Weed research in this direction needs to be promoted through APWSS activities, for better weed management in the Asian-Pacific Region.

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Technological Advances for Weed Management

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Introduction

Weeds are oftentimes the major pests of crop fields and farmers often utilize a variety of cultural, mechanical, and chemical methods to manage them. Herbicides have been the most preferred tool for weed management since the 1950s because these are significantly more efficient and economical over other weed management methods. The rapid growth of the herbicide industry and the industrial revolution in farm mechanization paved the way for large farm operations. Herbicides are indispensable for large farms.

The success of herbicide development and herbicide registration for crops hinges primarily on environmental safety and minimum off-target impact. Formulation and application technologies, coupled with sensible regulations, have mitigated the risks associated with herbicide use. The latent impact of herbicide use, with which we will continue to contend into the future, is ecological. It is inevitable that weeds will continue to adapt to selection pressure. This will be manifested as weed population shifts in the short-term and resistance evolution in the long-term. Resistance to herbicides will drive most of what we do henceforth for weed management and will also drive future discoveries of novel weed management tools. Breaking the yield ceiling, developing resilient varieties, efficient management of large farms, and improving the sustainability of crop production require a higher level of technological innovations. We are beginning to see such innovations today.

New Generation of Herbicide-Resistant Crops

Herbicide-resistant (HR) crops are mainstays of modern agriculture (Duke, 2005). Adoption of HR crop technology has far outpaced insect-resistance technology in the USA. Historically, developing herbicide resistance in crops has required long-term and nontrivial investigation into identifying, selecting, and breeding/transforming the trait into a target crop line that is well suited for the goals of the technology developer and farmer. Recent advances in the fields of genomics, proteomics, biochemistry, and computational science have enhanced biotechnology and herbicide technology development.

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Herbicide resistance may be endowed by one or more mechanisms including enhanced herbicide detoxification, target enzyme modification, or reduction in the absorption/translocation of an herbicide in the plant (Anderson, 2007). To develop a herbicide-resistant and high-yielding crop, both traditional breeding and genetic engineering are employed. Traditional breeding using chemical mutagenesis or whole-plant selection from diverse germplasm (Anderson, 2007; Duke, 2005) has yielded crops with resistance traits to single sites of action including acetyl coenzyme-A carboxylase (ACCase)- or acetolactate synthase (ALS)-inhibitor herbicides. Biotechnology ushered in transgenic crops starting with single resistance traits such as bromoxynil-resistant cotton in 1995 (Stalker *et al*., 1996), glyphosate-resistant (GR) soybean and cotton in the mid-1990s (Feng *et al*., 2010) and later on, glufosinate-resistant crops (Duke, 2005). Resistance to bromoxynil and glufosinate is from bacterial transgenes that detoxify the respective herbicides. Resistance to glyphosate is from a bacterial transgene that is insensitive to glyphosate.

The impact of GR crops has been monumental across all aspects of the agriculture sector, resulting in the greatest advancement in modern agriculture, but also the biggest hurdles that farmers face at a global scale. It simplified weed control like never before, with a single herbicide that is very cheap and most environmentally friendly among all other herbicides, but eventually also resulted in the most widespread and difficult herbicide-resistant weed problems to date (Green, 2012; Heap, 2017; Vencill *et al.,* 2012). Approximately 40% of producers in the US have adopted no-till or conservation tillage systems after the commercialization of GR crops, which has helped to improve soil properties(Wade *et al*., 2015). The evolution of resistance to glyphosate has forced many farmers to return to conventional tillage, and had increased the volume of herbicide use instead, in an effort to manage resistance reactively and proactively (Benbrook, 2012, Fernandez-Cornejo *et al*., 2014).

Investment into HR crop technology and herbicide discovery declined steeply following the release of GR crops in 1996 (Dill *et al*., 2008). However, due to increasing evolution of herbicide resistance and the need for diversification in agricultural production, new technologies have been, or are about to, be released. Acetolactate synthase-resistant soybean is not a new technology, but an enhanced trait (Bolt®) was released in 2015 with higher tolerance to ALS herbicides. This technology expands the registration of older herbicides and provides better options for management of problematic species. For the 2017 season, Inzen® *Sorghum bicolor* (L.) Moench ssp. *bicolor* (grain sorghum) was commercialized in the US, with traits endowing resistance to ALS inhibitors, specifically nicosulfuron and rimsulfuron. Nicosulfuron has been a standard post emergence grass herbicide for corn in the US due to its good control of *Sorghum halfpence* (L.) Pers. (Johnsongrass) and *S. bicolor* (L.) Moench ssp. *drummondii* (shattercane), but it could not be used on grain sorghum. The new technology provides growers with an option for controlling weedy *Sorghum* spp. in grain sorghum.

A new non-transgenic rice with resistance to ACCase inhibitors (Provisia®) will be commercialized in 2018. The target of this technology is weedy rice and other difficult-to-control annual grass species, such as barnyard grass (*Echinochloa* spp*.*). This technology will complement the current ALS-inhibitor-resistant rice technology, Clearfield® rice. These technologies take advantage of mutant target enzymes (ACCase and ALS), with reduced herbicide affinity. All HR traits will require good stewardship including crop rotation, to ensure long-term utility. The somewhat specific spectrum of these herbicides also leave room for other weed problems to arise.

Herbicide Trait Stacking

Stacked, or multiple-resistant, herbicide technology will become the key trait of new HR crops (Green, 2011, Green *et al*., 2008). Stacked resistance traits expand the herbicide options for in-crop application and ensures complete weed control. Tank-mixtures and premixed herbicides will increase the weed spectrum of a single application and reduce the costs associated with multiple herbicide applications. This approach is touted to reduce the rate of resistance evolution and improve the long-term efficacy of herbicides (Norsworthy *et al*., 2012). These technologies include dual-stacked traits such as resistance to glyphosate or glufosinaate + ALS inhibitor, glyphosate + glufosinate, 2, 4-D + ACCase inhibitor, and glyphosate + dicamba or 2, 4-D. Multi-stacked traits of three sites of action are also close to registration, or already registered, including resistance traits to: glyphosate + glufosinate + 2, 4-D, glyphosate + glufosinate + dicamba, and glyphosate + glufosinate + HPPD inhibitor resistance in major agronomic crops. Most of these products have been released, or will be released within the next several years.

Next Generation Herbicide Resistance Trait Development

Biotechnology and the production of new herbicide traits have expanded beyond selection of modified herbicide targets from bacteria or diverse germplasms. New strategies are being developed, and used, to assess novel mechanisms for HR crops. The development of dicamba and 2, 4-D resistance traits arose from investigations of the degradative processes used by bacteria to metabolize these compounds(Behrens *et al*., 2007; Wright *et al*., 2010). For dicamba, a soil bacterium was used to identify an enzyme responsible for degrading dicamba into non-toxic metabolites (Behrens *et al*., 2007). TfdA was a known catalyst for 2, 4-D metabolism in bacteria, but was not efficient to use in HR crop development. Bioinformatics tools allowed mining similar genes in other organisms, leading to the identification of AAD-12 from *Delftia acidiovorans*, which was used to transform crops for resistance to 2, 4-D (Wright *et al*., 2010).

This enzyme, which catalyzes the cleavage of the oxygenolytic bridge of most auxinic herbicides, also cleaves a similar link in aryloxy-phenoxy-propionates endowing multiple-resistance to ACCase herbicides in monocot species. This is the first HR crop technology involving a single gene that endows resistance to more than one mode of action. Modified herbicide targets have been discussed previously. However, a novel approach for identifying, isolating, and 'building' an enzyme cassette was developed to achieve resistance to 4-hydroxy-phenyl-pyruvate dioxygenase (HPPD) inhibitors in soybean (Siehl *et al*., 2014).

Most recently, BASF Corporation disclosed a novel protoporphyrinogen oxidase (PPO) enzyme that is insensitive to PPO inhibitors, which was developed utilizing protein chemistry and structural biology (Aponte *et al*., 2017). The 3-D structure of the PPO enzyme was resolved and used as a model to design new herbicides targeting this protein. The novel mutant enzyme could tolerate all known PPO herbicides, but functions normally in corn and soybean. Advances in the molecular biology, genomics, proteomics, and bioinformatics have been very beneficial to weed science and the development of HR crops.

Herbicide-Resistant, Resilient Crops, and the Future of Agriculture

Agricultural scientists and practitioners generally believe that herbicide-resistant (HR) crops have been important in advancing agriculture in the last 20 years. This technology is likely to dominate food production into the next 50 years. Recent discoveries in plant genomics and advancements in plant biology have led to significant changes in the methods used to develop HR crops.

These techniques could improve weed management and crop adaptation to abiotic and biotic stresses. Weeds have an inherent biological diversity and genetic plasticity that crop species lack, giving them a more strategic advantage under adverse conditions. The importance of HR crops will only increase with time, as weeds continue to evolve and adapt. Global climate change, resulting in increased atmospheric temperatures and CO_2 concentrations, will inevitably lead to several weedy species acquiring increased competitive advantages. Losses of prime agricultural land to industrial development and urban sprawl will push agriculture into marginal lands, where weed impacts are likely to be severe, and diminish the total production area altogether. These scenarios require tougher, resource-efficient, high-yielding crops.

New herbicides alone will not solve food shortage nor sustain sufficient food production. Producers will need to use these technologies as one tool for weed management, together with other tools. It is important that herbicide and HR crop technologies continue to advance; however, it is also equally important that tolerance to abiotic and biotic stress and competitive traits be incorporated into HR crops. Thus, future crop varieties will contain improved agronomic traits in addition to stacked herbicide resistance traits. Implementation of stewardship and best management practices aimed at disrupting the biology of weedy species will be necessary to keep in step with evolving weed problems.

Crops Resistant to Parasitic Weeds

Parasitic weeds can cause up to 90% crop yield loss and are arguably the most-difficult-to-control among weedy plants because of their physical, biochemical, physiological, and genetic connection with their host plants (Aly, 2007). The most notorious parasitic plants include numerous species of *Orobanche* spp. (broomrape), *Striga* spp. (witchweed), and *Cuscuta* spp. (dodder). Conventional weed control strategies, whether cultural or chemical, do not work well on these weeds because their seeds germinate only upon exposure to certain compounds (collectively known as strigolactones) exuded from roots of host plants such as strigol from various species including *Gossypium hirsutum* L. (cotton), or sorgolactone from *S. bicolor* (Yoneyama *et al.*, 2010). Developing a parasite-resistant crop is being pursued. Traditional breeding for parasite-resistant crops generally has not been successful, or severely limited by the few number of resistance genes identified such as in sunflower and sorghum (Rispail *et al.*, 2007).

Biotechnology had been used previously to generate a transgenic maize that exudes minimal amount of germination stimulant by inhibiting the terpenoid biosynthesis pathway (Matusova *et al.*, 2005). Advances in the next-generation-sequencing (NGS) technology, genomics, proteomics, and metabolomics coupled with advanced softwares for bioinformatics, will allow a comprehensive understanding of the molecular basis of host-parasite interaction. Besides the identification of host-parasite signaling genes, there is increasing evidence of horizontal gene transfer between host and parasitic weed (Kim and Westwood, 2015; Yoshida *et al.*, 2010). These will reveal novel techniques for developing parasite-resistant plants with new gene targets.

RNA Interference (RNAi) Technology

Advancing technology is necessary to improve plant physiology to better adapt to abiotic and biotic stressors including herbicide application. Plant cells have intrinsic mechanisms to turn off expression of harmful genes, modulate responses to abiotic and biotic stressors, maintain genome integrity, adapt, or regulate developmental processes through non-coding, small RNA molecules that differ in their biosynthesis (Khraiwesh *et al.*, 2012).

The process, collectively called RNA interference, is attained either through short, interfering RNA (siRNA) or microRNAs (miRNA) (Sanan-Mishra *et al.*, 2013). RNA interference represents a genetic process that occurs naturally in many eukaryotes and can be modified to attain genetic modification in a large variety of economically important plants (Rutz and Scheffold, 2004). This process can be done artificially to manipulate the expression of genes of interest. It has been discovered that naturally occurring micro-RNAs (miRNA) can effect complex gene regulation by binding to reverse complementary sequences, resulting in cleavage or translational inhibition of the target RNAs (Khraiwesh *et al.*, 2012). siRNAs have a similar structure, function, and biogenesis as miRNAs, but are derived from long dsRNAs and can often direct DNA methylation at target sequences (Khraiwesh *et al.*, 2012).

Some miRNAs increase the expression of certain genes in response to plant developmental needs, or to stress factors (positive trait regulators), while others suppress gene expression (negative trait regulators) to turn off gene products that are not needed (Zhou and Luo 2013). Thus, artificially modulating the expression of miRNA can alter plant traits. A promising application of this technology in weed management would be related to increasing the tolerance to oxidative stress in crops. For example, it has been shown that overexpression of a negative regulator, such as the miR398 form of *CSD2* (Cu/Zn SOD gene) by RNAi increased plant tolerance to oxidative stresses (Sunkar *et al.*, 2006). The resultant trait could lend crop tolerance to some herbicides.

In the same manner, the competitive ability of crops can be improved by modifying the expression of miRNAs that control nitrogen metabolism (Fischer *et al.*, 2013) and tolerance to drought (Ferdous *et al.,* 2017), salt stress (Zheng and Qu, 2015), or other stress factors. The critical first step governing all these is identifying the appropriate miRNA target, which entails understanding the impact of modulating the target gene expression on plant phenotype across key species and environments.

Gene and Genome Editing

Genome editing allows precise manipulation in the genome of an organism using sequence-specific nucleases. Nucleases create specific double-strand breaks at desired locations in the genome. The most rapidly emerging genome editing tool is the Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR)/Cas9 system from *Streptococcus pyogenes*, which is based on RNA-guided engineered nucleases (Jinek *et al*., 2012). There are other genomic editing tools such as zinc finger nucleases (ZFN) and transcription activator-like effectors nucleases (TALENS) but the CRISPR/Cas9 system is the fastest, cheapest, most versatile, and most reliable system for gene editing (Abdallah *et al*., 2015; Bortesi and Fischer, 2015).

This tool can accelerate crop breeding by allowing the precise and predictable modifications of desired traits directly in an elite background. Modifying the native herbicide-target gene can endow resistance to a herbicide. Deletion of PPO Gly210 in weedy *Amaranthus* endows resistance to PPO herbicides (Patzoldt *et al*., 2006; Salas *et al*., 2016). Deleting this Gly_{210} codon using genomic editing tool can provide tolerance to PPO herbicides in crops. The CRISPR/Cas9 system can be programmed to increase gene expression, silence an undesirable gene, or modify trait stacking (e.g. tolerance to disease + herbicide) (Li *et al*., 2013) including tolerance to other stresses such as drought.

One of the consumer objections to GM crops is the presence of a selectable marker, usually a foreign gene associated with the introduced trait. Dual targeting by CRISPR/Cas9 achieved precise excision of transgenes from the rice genome (Srivastava *et al*., 2017); thus, generating marker-free plants. This means a resistance trait from a weedy relative (or a germplasm variant) of the same species can be placed into a crop cultivar through genetic engineering, and the external genes (i.e. selectable markers) associated with the modification can be removed from the transformed cultivar line. Complete removal of the marker genes by genomic editing should alleviate the regulatory burden associated with transgenic plants, which until today, has hampered the development of HR rice.

Off-target activity is a major concern in genome editing. The specificity of CRISPR/Cas9 is determined by technology, the sequence of the guide RNA and the DNA target. A perfect match between the last 8-12 bases of the guide RNA sequence is needed for target site recognition and cleavage(Cong *et al*., 2013; Jinek *et al*., 2012). Careful selection of specific guide RNA sequences should minimize the risk of unwanted genomic modifications(Bortesi and Fischer, 2015). New techniques have been developed to avoid or minimize off-target mutations by Cas9 (Bortesi and Fischer, 2015; Fu *et al*., 2014; Shen *et al*., 2014). While off-target activity varies among cell types and species, whole genome sequencing analysis in *Arabidopsis* and rice revealed almost negligible mutations at off-target sites (Feng *et al.*, 2014; Zhang *et al.*, 2014). Substantially higher mutation rates, 117 indels and 1,397 single nucleotide variants, were observed in non-homologous gene sequences in CRISPR-treated mice. These rates are much higher than observed in spontaneous germline mutations, raising concern by the researchers and warranting further investigation of CRISPR- based research.

Genomics, Bioinformatics, and the 'Next-Generation' Tools

Weed Science has long been a bystander in the advances of basic science due to a lack of funding to develop resources for non-model organisms and from a deficiency in cross-disciplinary research that can expand into new research areas. Recent advances in next-generation-sequencing (NGS) technology and computational science have made not only the investigation of genomes of organisms less expensive, but also introduced new low-barrier tools for researchers. Utilization of these technologies in research has expanded globally in the fields of weed biology, invasiveness, stress adaptation, and more importantly-evolution of herbicide resistance.

Advancing to the Next Generation

Genomics in Weed Science is used in two broad areas: (1) classical molecular biology and (2) functional genomics (for comprehensive review, see Bodo Slotta, (2008). Classical molecular biology approaches involve sequencing and characterizing the genome of an organism. Genomic sequence and structure information as well as parameters associated with sequence diversity are used for phylogenetic assessments, gene flow studies, species relationships and population genetic studies, species identification, evolution of weedy traits, evolution of resistance to herbicides, and others. These classical approaches have been critically important in the early development of genomics tools in Weed Science, facilitating the identification of genes involved in herbicide modes of action. Using some of the principles developed in classical molecular biology, advances have been made into next generation technology that expand on our knowledge and understanding of weed biology.

Functional genomics informs us on the function of genes and in the process, enables understanding what controls phenotypic traits, such as weediness. Expressed sequence tag (EST) libraries (Basu and Zwenger, 2009) are among the earliest tools used for comparative gene expression and comparative genetic analysis of some weed species. This was followed by the development of DNA microarrays (Eisen *et al.*, 1998), which allow genome-wide analysis of differential gene expression in response to biotic or abiotic stressors. This technique allows identification of expressed genes, which are quantified relative to a reference constitutively expressed gene. While this technique was used for a variety of research in weed science, its cost and complexity limit the identification of every potential gene of interest and the broader analysis of gene networks (Lee and Tranel, 2008). Its main limitation is the lack of available GeneChips for weedy species.

The most recent advancements in DNA sequencing and functional genomics are facilitated by NGS. NGS technology encompasses methods by which the genome of an organism is sequenced in a high throughput manner using a DNA template from short pieces of cDNA that are sequenced, imaged, aligned, and assembled into a contiguous genome (Metzker, 2010). Several NGS methodologies have been developed, including 454 pyrosequencing and genotyping by sequencing (GBS). Both DNA and RNA can be sequenced using NGS technology, allowing the assembly of an organism's genome, transcriptome, or proteome. It enables the study of non-model species because it does not require complete reference genome.

For Weed Science, the transcriptome produced with RNA-sequencing (RNAseq) provides an unprecedented global view of how weedy species modify gene expression in response to agro-ecological conditions, including management interventions (Wang *et al*., 2009). The genome, transcriptome, or proteome for an organism can be assembled from NGS data using bioinformatics tools. Weed scientists are now using this technology to investigate genomic assembly (Yang *et al*., 2013), herbicide resistance evolution and stress adaptation (Gaines *et al*., 2014; Nah *et al*., 2015; Yang *et al*., 2013), and novel herbicide target genes (Riggins *et al*. 2010). This enabled identification of target-site and non-target-site gene groups associated with herbicide resistance. Investigation into non-target-site resistance mechanisms of diclofop-resistant *Lolium rigidum* using RNAseq identified four metabolism-related transcripts associated with herbicide detoxification (Gaines *et al*. 2014).

Advancing the discipline of Weed Science and discovering novel tools for weed management requires critical evaluation of the biology and physiology of weedy species using genomic methods. By integrating classical and next-generation technologies we can identify novel herbicide sites of action or herbicide targets, novel (perhaps nonchemical) means of weed control, and novel genes to use for improvement of crop competitive traits, weed-suppressive traits, and tolerance to stress.

Remote Sensing, Robotics and Drones

Weed scouting to assess dominant weed species and their distribution within a field is necessary to guide the selection of suitable herbicide options. Weed scouting is expensive, time consuming, and weather-dependent. Remote sensing has the potential to provide an efficient and convenient alternative for weed scouting to optimize crop management. Remote sensing utilizes satellite or manned/unmanned aircrafts for capturing data. Satellite-based remote sensing is well suited for surveying a large area and large-scale crop yield monitoring (Zhang *et al.*, 2005). Satellite imagery lacks precision in assessing small areas, especially for weed detection, spatial distribution, and herbicide injury evaluations. These tasks require high- resolution imagery, which is typically achieved by closer observations using manned/unmanned aircrafts or ground vehicles.

Ground-based sensors have been used in the past to investigate the use of machine vision for weed detection and precision herbicide delivery (Hagger *et al.*, 1983). Machine vision technologies can facilitate site-specific, or spot applications of herbicides and reduce the amount of herbicide used (Medlin *et al.*, 2000). Ground-based optical sensors (such as Greenseeker®, WeedSeeker®) have been used to identify plants based on the surface reflectance of green tissues in agricultural fields (Andújar *et al.*, 2011; Franz *et al.,* 1991). Hagger *et al.* (1983) tested the first reflectance-based plant sensor for spraying weeds. This sensor measured the radiance ratio of red (R) and near infrared (NIR), which is typically higher for green surfaces, compared to bare soil. Hummel and Stoller (2002) evaluated a commercial weed sensing system (WeedSeeker®) attached to a sprayer and reported an average 45% saving on glyphosate use in corn and soybean in the US Corn Belt.

Utilization of optical sensors, or reflectance-based sensors for herbicide applications has been studied globally (Lamm *et al.*, 2002; Midtiby *et al.*, 2011). However, optoelectronic sensors are not capable of discriminating between weed species (Sui *et al.*, 2008) and can be used only in specific situations where broad-spectrum herbicides (such as glyphosate, paraquat) are to be applied. Site-specific herbicide applications require a more strategic approach to use selective herbicides for specific weed situations, instead of a simple broad-spectrum control. More recently, Fennimore *et al.* (2016) developed a commercial ground-based machine vision system that can remove intra-row weeds, as well as thin crops to desired stands based on row crop patterns. However, this system cannot differentiate weeds from crops if weeds are large or dense.and ground-based weed detection systems lack broad spatial scale information.

Integration of unmanned aerial systems (UAS) platforms (fixed-wing as well as rotary-wing) offer solutions to some limitations of satellite- or manned-aircraft-based remote sensing as well as ground-vehicle-based sensing. The applications of UAS have been increasing in forestry (Wallace *et al.*, 2012), rangeland ecology (Laliberte *et al.,* 2010), and agronomic cropping systems (Lelong *et al.*, 2008), among several other fields. Multispectral and hyperspectral imaging sensors mounted on unmanned aerial vehicles (UAVs) have been used successfully to detect weeds and distinguish species (Peña *et al.*, 2013). Multispectral and hyperspectral imaging can provide valuable information that is not obtained by RGB cameras or not visible to the naked eye. In particular, hyperspectral imaging has been used more often to classify agricultural systems and vegetation because it has more bands compared to that of multispectral sensors.

Hyperspectral remote sensing collects reflectance data over a wide spectral range through narrow bands (10 nm) (Mulla, 2013) and is advantageous over other sensors when small differences are to be detected. Hyperspectral imagery analysis carried out at College Station, TX indicated that *Amaranthus palmeri* (S.) Wats. (Palmer amaranth), *A. tuberculatus*(Moq.) Sauer (waterhemp), and *Echinochloa crus-galli*(L.) P. Beauv. (barnyardgrass) can be distinguished at 700 – 1000 nm wavelength (Bishop *et al.,* unpublished data). Similar studies have distinguished *T. aestivum* from broadleaf weeds; *Glycine max* (L.) Merr. (soybean), *Sida spinosa* L. (prickly sida), *Senna obtusifolia*(L.) Irwin & Barneby (sicklepod), and *Ipomoea lacunosa* L. (pitted morningglory) (Gray *et al.*, 2009); *S. bicolor*, *Amaranthus* spp., *Echinochloa* spp., and *Cyperus rotundus* L. (purple nutsedge) (Che'Ya, 2016); and several other weeds (Yang and Everitt, 2010).

Hyperspectral imagery also has the potential to differentiate herbicide-resistant and susceptible weed biotypes. Jha *et al.* (2017) utilized hyperspectral imagery to differentiate *Kochia scoparia* (L.) Schrad. (kochia) biotypes resistant to glyphosate or dicamba from susceptible biotypes. Differential reflectance values were observed near 720 nm for susceptible and dicamba-resistant kochia. The management of herbicide-resistant weeds will be easier if resistant plants could be detected in a field during early stages of evolution. More research is necessary in this area to develop robust hyperspectral imagery-based early detection systems for herbicide-resistant weeds.

Nanotechnology

Nanomaterials have found unprecedented utility in various fields of science including medicine, manufacturing and material construction, chemical formulation, delivery of molecules into cells, sensors, and others. It has opened unchartered territories of scientific investigations in agriculture (Kanjana, 2015). Being 100 nm or less in size, nanoparticles have large surface area:volume ratio enabling applications that were formerly untenable (NSTC 2017). Nanoparticles exhibit unique properties that have been found useful, for instance, in producing slow-release fertilizer and pesticide formulations, or formulations that offer protection from rapid biotic or abiotic degradation and reduced run-off because of increased sorption properties (Ghormade *et al.*, 2011; Gogos *et al.*, 2012). These would be among the most immediately recognizable applications. Despite its exciting potential for generating novel tools for weed management, nanomaterials and nanotechnology should be used with caution. Its risk to humans, flora and fauna, and the environment should be assessed thoroughly.

Herbicide formulations

The use of nanomaterials in herbicide formulations is deemed to increase herbicide efficacy by improved absorption and translocation of herbicide in the plant, increase the adsorption of herbicide onto clay particles thereby reducing runoff or potential contamination of ground water, or protect the herbicide from microbial or UV degradation thereby increasing the residual activity. Nano formulations that have been commercialized so far are micro emulsions (ME). These are typically 10 - 50 nm in size, demonstrating one type of nanotechnology application in pesticide formulation (Gogos *et al.*, 2012).

Some specific examples in this category are fomesafen 1.88SL or 2SL (by Syngenta Crop Protection), a premix of fluroxypyr + clopyralid + MCPA (Greenor®, by Dow AgroScience) and a premix of S-metolachlor + metribuzin (Tailwind®, by MANA Crop Protection). The adjuvant business is also working on developing novel formulations with nanotechnology. One example is the adjuvant marketed as Nano Excel for Herbicide developed by Enviro Science Technologies (http://estchemicals.com/nano-tech/nano-excel-for-herbicide/) specifically for glyphosate and 2, 4-D for use in turfgrass.

Herbicide Sensors and Tracers

Now, more than ever, agriculture practitioners (specifically those using herbicides or other pesticides) need to be more vigilant in minimizing potential negative impact on the environment. Significant resources have been devoted to monitoring the dissipation and off-target movement of pesticides. The commercialization of HR crops containing dicamba- or 2, 4-D-resistance traits underscores the need for highly sensitive, cost-effective, high-throughput methods to monitor these compounds (or other pesticides) in the air, plant, and water. Traditional analytical methods involving liquid or gas chromatography are complex and costly (Jankowska *et al.*, 2004). Recently, Rahemi *et al.*, (2015) simultaneously modified a glassy carbon electrode with a novel polyaniline (PANI)-carbon nanotube (CNT) cyclodextrin matrix. The modified electrode was used to analyze MCPA and its metabolite 4-chloro-2-methylphenol, as precisely and accurately as the HPLC method, and was simpler and cheaper to prepare.

Different sizes, and metals, of semiconductor nanocrystals (quantum dots, QDs) emit different colors of light when exposed to UV radiation as a manifestation of quantum confinement effect (Saleh and Teich, 2013). QDs are both photo-luminescent and electro-luminescent. Coupled with their ability to penetrate cell walls and cell membranes, QDs can be effective tracers of chemicals or biomolecules in plants; thus, presenting the possibility of replacing the use of radioactive tracers in studying herbicide entry, movement, and metabolism in plants. Such studies are conducted traditionally with radio-labelled herbicides (Nandula and Vencill, 2015), which is a lengthy, laborious, costly process that comes with high potential hazard. As with radio-labelled tracers, QDs can help locate the organelle and molecular target of a herbicide or the destination metabolites. Gold nanostructures, through two-photon microscopy, have been effective as imaging platforms in plants, because of their low cytotoxicity (Jia *et al.*, 2016). Recently, Jia *et al.* (2016) demonstrated for the first time that gold nanorods (39.4 nm x 11.3 nm) can be used as fluorescent tracer for 2,4-D herbicide using tobacco (*Nicotiana tabacum* L.) as test plant.

Herbicide Delivery

Among the earliest commercial applications of nanotechnology in agriculture is the development of controlled release formulations of agrochemicals (Loha *et al.*, 2012; Grillo *et al.*, 2012). Gradual release of a herbicide in soil translates to beneficial effects including prolonged effective activity and reduced losses via leaching, runoff, volatilization, or UV degradation (Pereira *et al.*, 2014). Many soil-applied herbicides have short half-lives. For example, flumioxazin, imazethapyr, *S*-metolachlor, and thiobencarb have half-lives of 12–18 d, 60–90 d, 15–50 d, and 30-90 d in soil under aerobic conditions, respectively (Shaner, 2014). Thus, follow-up application of other herbicides are needed generally within one to two months of applying residual herbicides.

If the herbicide molecule is released gradually, and distributed evenly in the root zone by the nanocarriers, it allows for better interaction with plant roots resulting in increased absorption and less probability of being moved off-site by runoff or leaching. Pereira *et al.,* (2014) reported higher activity of atrazine nanocapsules in the 0- to 4-cm soil depth than that of conventional atrazine formulation. Further, the atrazine nanocapsules had more activity on the sensitive species at lower quantity than conventional atrazine. The nano formulated atrazine did not injure corn. Thus, they demonstrated that the herbicide load in the environmental can be reduced by using nanoparticles to deliver herbicides, without sacrificing the level of weed control. The ability of nanocarriers to penetrate cell walls and cell membranes has sparked hopes for the development of systemic herbicide formulations (Aly, 2007), or even peptides (Perez-de-Luque and Rubiales, 2009) or RNAi agents that would be effective on parasitic weeds.

Just as the utility of nanotechnology in generating novel tools for weed management bears promise, the uncertainties are equally high. There is so much that we do not know yet about the fate of nanomaterials in the environment and plants and its safety on humans (and animals in general). When it pertains to food, feed, and fiber, consumers are averse to technologies they do not understand. It is logical to expect that nanotechnology in agriculture will run into the same road blocks as GM crops. The idea of applying tons of nano-carriers with fertilizer or spraying large volumes of nano-pesticide mixtures across vast agricultural lands is unnerving.

Concluding Remarks

The study of genomics, proteomics, metabolomics, bioinformatics, systems biology, molecular biology, and physiology and their applications into biotechnology, crop improvement, weed management, plant identification tools, molecular assays, and others will have the broadest impact on weed science and agriculture. Stacking of traits in crops will become the norm. miRNAs will be utilized more in developing crop traits. Advances in miRNA technology is most limited by the discovery of appropriate targets, which is now starting to be overcome by NGS technology.

NGS allows us to address questions in weed science that we could not investigate before, such as the molecular mechanisms driving weed evolution and adaptation as well as the intricate interaction between crops and weeds. The simplicity, accessibility, versatility, and robustness of CRISPR/Cas9 technology will facilitate forward and reverse genetics, enhance research in model organisms, and speed up gene discovery and trait improvement in plants. This technology has vast applications, but we should be mindful of potential consequences. The extent of off-target modification needs to be investigated thoroughly.

Control of parasitic weeds is another area where novel tools are much needed. There is hope that various 'OMICS' tools will accelerate development in this area where traditional plant breeding has failed thus far in producing varieties resistant to infection by parasitic plant (Aly, 2007). Applications of nanotechnology in agriculture will increase and would likely continue to facilitate the delivery of RNAi agents for nonchemical weed control technology and deliver novel herbicide formulations. Remote sensing and robotics will most likely become a more practical, user-friendly, and affordable tool. Integration of color, shape, and textural features will improve the effectiveness of weed species detection with high-resolution images produced using UAS-based sensors (e.g. Downey *et al.*, 2004; Zhang and Chaisattapagon, 1995). The future holds great promise for developing novel tools for weed management in particular and producing crops efficiently in general. Technology is advancing fast; we are limited only by our imagination.

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Ringing the changes on the taxonomy of *Echinochloa* (L.) P. Beauv. (Barnyard grass) in the Asian-Pacific region

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Abstract

A revised key to the identification of taxa of *Echinochloa* in the Asian-Pacific region is presented, updating a key that was published in 2001. The revision is the result of many years of taxonomic studies of this important weedy genus, and was based on collections made in the region, and elsewhere. The revision emphasizes the importance of scientific associations between scientists in the region, promoted by the 'inter-changes' within the Asian-Pacific Weed Science Society.

Key words: *Echinochloa*, barnyard grass, Asian-Pacific grasses

Introduction

The inauguration of the Asian-Pacific Weed Science Society (APWSS) at the Asian-Pacific Weed Control Interchange in 1967 coincided with the beginning of my serious interest in the taxonomy of *Echinochloa*. After a year in Japan in 1965, on a technical scholarship at the National Institute of Agricultural Sciences in Tokyo, where I learnt much about one form of *Echinochloa*, now known as *E. oryzicola* (*tainubie* in Japan), I was keen to find out whether it occurred in Australia. This led me into a field of surprises. Contrary to the belief held by grass botanists in Australia that all of our barnyard grasses were exotic, Australia did have a number of native species, as Dr. Joyce Vickery–distinguished grass taxonomist of the National Herbarium of New South Wales (NSW–and I found out, in our detailed studies of Australian and exotic collections. Only one of these had been noted as a weed in rice.

In my annual report for 1966, in dealing with my studies on *Echinochloa*, I drew attention to the confused state of the taxonomy of the genus, noting that I was "in the process of trying to elucidate (with the help of plants grown from seed) some of the problems involved," which I expected would "take some time in view of a number of difficulties, not the least being the relative inaccessibility of the relevant literature." In those days I was working in the Ecology Section of the Division of Plant Industry at the Commonwealth and Scientific Research Organisation (CSIRO) in Canberra, ACT, where I was encouraged in my work by the staff of the Herbarium, now included in the Australian National Herbarium (CANB). On my moving to the Faculty of Agriculture, at the University of Sydney, in 1969, I was able to continue my work in closer association with Dr. Vickery.

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My first association with the APWSS was at the Fourth Conference held in 1973 at Rotorua, New Zealand, where I presented a paper, my first on *Echinochloa* in the Asian-Pacific region, and again met Japanese delegates, who I had first been introduced to in 1965 in Japan. Since then I have received help and suggestions from various members of the Society and from others in the countries it represents.

Attending APWSS conferences has enabled me to collect *Echinochloa* in New Zealand, Japan, the Philippines, and India. Visits to herbaria in these countries, as well as herbaria in St Petersburg (Leningrad), Europe and the United States, have been of great benefit. Special collecting trips in the Philippines, Indonesia and Burma (Myanmar) have given me a good appreciation of the distribution and variation of the species. I must acknowledge, too, the great support I have had in Australia, especially in relation to travelling costs.

The main purpose of this chapter is to present a revised key to *Echinochloa* in the Asian-Pacific region. My first key (Michael, 1983) was the first attempt to put the world members of the genus in proper focus, the second key (Michael, 1994) included only *Echinochloa* in China, and the third key (Michael, 2001), here revised, included species and varieties in the Asian-Pacific region. It is important for readers to absorb the contents of the notes in these three attempts, as background to my new key. In this chapter I have made comments on only some taxa.

My recent publications on *Echinochloa* have included accounts of the genus in North America north of Mexico (Michael, 2003a), in the Asian-Pacific region (Michael, 2003b) and in Australia (Simon *et al*., 2009). A great inspiration has been the revised edition of studies on the natural history of *Echinochloa* (Yabuno and Yamaguchi, 2001). It would be good to have an English translation of this thoroughly satisfying book. Additional useful contributions to the taxonomy of *Echinochloa* are to be found in Kim and Labrada (2003).

List of the origin of *Echinochloa* taxa in the Asian-Pacific region

World tropics

E.colona (L.) Link

Eurasia

E.crus-galli (L.) Beauv. var. *crus-galli*

Asia (including South-East Asia, Indonesia, New Guinea & adjacent islands)

E. caudata Roshev.

E. crus-galli (L.) Beauv. var. *praticola* Ohwi.

E. crus-galli (L.) Beauv. var. *hispidula* (Retz.) Honda

E. crus-galli (L.) Beauv. var. *austro-japonensis* Ohwi

E .crus-galli (L.) Beauv. var. *formosensis* Ohwi

E. crus-galli (L.) Beauv. var. *persistens* Diao

E. crus-galli (L.) Beauv. var. *oryzoides* (Ard.) Lindm.

E. esculenta (A.Br.) Scholz

E.frumentacea (Roxb.) Link

E. mentiens P.W.Michael
E. oryzicola (Vasing.) Vasing
E. picta (Koen.) P.W. Michael
E. stagnina (Retz.) Beauv.
E.trullata P.W. Michael

Australia
E.dietrichiana P.W. Michael
E. elliptica P.W. Michael et Vickery
E.inundata P.W.Michael et Vickery
E. kimberleyensis P.W. Michael et Vickery
E.lacunaria (F.Muell.) P.W.Michael et Vickery
E.macrandra P.W. Michael et Vickery
E. telmatophila P.W. Michael et Vickery
E.turneriana (Domin.) J.M. Black

Africa
E. pyramidalis (Lam.) Hitchc. et Chase

North America
E. muricata (Beauv.) Fernald var. *microstachya* Wiegand

South America
E.crus-pavonis (Kunth) Schult.
E. polystachya (Kunth) Hitchc.

Revised key to *Echinochloa* in the Asian-Pacific region

NB. Spikelet length measurements do not include awns

A. Annuals

1.	Spikelets 3 to 5 mm long.	2.
1.	Spikelets less than 3 mm or greater than 5 mm long.	18.
2.	Ligule a line of bristles or fine short cilia.	3.
2.	Ligule absent, or the ligular regions bearing a few cilia or fine pubescence.	4.
3.	Numerous long bristles at nodes of inflorescence. Panicle spindle-shaped, up to 15 cm long. Spikelets narrowly elliptical. Awns of lower lemma up to 30 mm long, of second glume up to 10 mm long.	*E. elliptica*
3.	No long bristles along main axis or branches of panicle. Panicle narrow, linear. Spikelets broadly ovate or ovate-elliptical.	*E. turneriana*

4.	Spikelets broadly ovate, crowded along the often incurved branches of the inflorescence. Fertile florets and caryopses markedly humped, so that the second glume often appears to be shorter than the spikelet. Mature fertile florets not easily deciduous.	5.
4.	Fertile floret and caryopses not markedly humped.	6.
5.	Spikelets brownish at maturity. Commonly awnless, sometimes awned. Caryopses brownish.	*E. esculenta*
5.	Spikelets pale green at maturity, awnless. Caryopses whitish.	*E. frumentacea*
6.	Essentially obligate weeds of rice or crop plants in rice fields. Close tufted erect habit. Greatly resemble rice before flowering.	7.
6.	Not obligate weeds of rice, but all growing in wet places and often occurring in rice. Plants more or less spreading at base.	11.
7.	Panicle narrowly linear with alternate branches up to 25 mm long pressed closely to the primary axis. Spikelets around 3.5 mm long, caryopses 2–2.3 mm long, brownish.	*E. mentiens*
7.	Panicles erect or nodding, branches not pressed closely to the primary axis.	8.
8.	Spikelets 3–4 mm long.	9.
8.	Spikelets 3.5–5 mm long.	10.
9.	Spikelets 3–3.5 mm long. Lower lemma convex, hard and shiny. Awnless or less often awned, occasionally found on banks and fallow land.	*E. crus-galli* var. *formosensis*
9.	Spikelets 3–4 mm long, persistent, lower glume 0.22 length of spikelet. Leaf sheaths glabrous.	*E. crus-galli* var. persistens
10.	Spikelets broadly ovate to ovate. Inflorescence hanging almost horizontal at maturity. Spikelets nearly always awned. Awns sometimes as long as 50 mm. Lower glume 0.33–0.5 the length of spikelet. Collar region of leaves rarely with tufts of hairs. Caryopses ovate, embryo 0.7–0.8 the length of the caryopsis.	E. crus-galli var. *oryzoides*
10.	Spikelets ovate-elliptical. Inflorescence more or less erect at maturity. Spikelets awned or awnless. Lower glume 0.5–0.66 length of spikelet. Lower lemma often convex, hard, and shiny. Collar region of leaves often with tufts of hairs. Caryopses oblong, embryo often 0.9 or more the length of the caryopses.	*E. oryzicola*
11.	Lemma and palea of fertile floret acute or acuminate with stiff tip. Panicle spreading, erect. Caryopses yellowish. Spikelets 3–3.5 mm.	*E. muricata*var. *microstachya*
11.	Lemma of fertile floret with withering tip sharply differentiated from the body of the lemma.	12.
12.	Panicle erect, ovate-triangular. Spikelets 2.5–3.5 mm long, crowded, awnless, falling very readily at maturity.	*E. trullata*
12.	Panicle erect or nodding. Spikelets short- or long-awned, sometimes apparently awnless but, if so, there are always a few awned at the ends of the racemes.	13.
13.	Inflorescence strongly drooping at maturity, sometimes bending over as much as 180 degrees. Spikelets crowded with short, curved awns, mostly 3–10 mm long, but can be up to 15 mm long.	*E. crus-pavonis*
13.	Inflorescence often nodding but not strongly drooping at maturity.	14.

14.	Spikelets narrowly elliptical, up to 4.2mm long. Awns of lower lemma up to 40 mm long. Awn on the second glume up to 7 mm long or longer. Bristles on spikelets not spreading. Leaf sheaths glabrous.	*E. telmatophila*
14.	Spikelets broadly ovate to elliptical, never narrowly elliptical, almost awnless, short- or long-awned.	15.
15.	Spikelets ovate or ovate-elliptical up to 5 mm long. Panicle linear, anthers 1 mm or more long.	16.
15.	Spikelets broadly ovate, ovate, or ovate-elliptical, 3–4 mm long. Long bristles abundant along main axis and branches of panicle. Panicles various, often pyramidal. Anthers generally less than 1 mm long.	17.
16.	Spikelets ovate, uniformly 3 mm with strongly spreading bristles up to 1 mm long. Long bristles prominent at point of attachment of racemes and along main axis. Panicles not becoming purplish.	*E. dietrichiana*
16.	Spikelets 3.5–5 mm long, with few or no bristles on main axis and/or branches of panicle.	*E. inundata*
17.	Spikelets broadly ovate or ovate. Awnless except at the ends of branches, short-awned or long-awned. Lower lemma flat, occasionally convex and shiny. Caryopses ovate. Panicles of variable length, more or less erect, often pyramidal, sometimes nodding, branches never obviously whorled. Long panicles, often with secondary branches on lower primary ones.	*E. crus-galli* var. *crus-galli*
17.	Spikelets ovate-elliptical, short or long awns. Caryopses more or less oblong. Panicles rarely pyramidal, erect or nodding, branches often whorled, more or less erect except for the lowermost ones.	*E. crus-galli* var. *hispidula*
18.	Spikelets 5 mm long or longer.	19.
18.	Spikelets 3 mm long or shorter.	22.
19.	Spikelets with awns up to 90 mm long. Anthers more than 1.5 mm long. Ligule a line of bristles or cilia.	20.
19.	Spikelets awnless or awned. Ligule absent, rarely a line of short cilia.	21.
20.	Anthers 1.5–2 mm long. Palea of lower floret about half the length of the lemma, sometimes absent. Lower floret neuter.	*E. kimberleyensis*
20.	Anthers 2–2.8 mm long. Palea of lower floret about length of lemma. Lower floret staminate.	*E. macrandra*
21.	Spikelets awnless, ovate, very finely pubescent. Main axis and short branches of inflorescence without bristles.	*E. lacunaria*
21.	Spikelets awned, ovate. Panicles hanging more or less horizontally at maturity. Awns up to 50 mm long. Obligate weed of rice.	*E. crus-galli* var. *oryzoides*
22.	Palea of lower floret absent of poorly developed. Spikelets dense, 1 mm broad, with awns up to 45 mm long. Panicles up to 20 cm long.	*E. caudata*
22.	Palea of lower floret fully developed.	23.

23.	Spikelets broadly ovate to ovate, awnless with panicle not more than about 15 cm long.	24.
23.	Spikelets ovate-elliptical to elliptical, usually with short awns. Inflorescence close, short with more or less erect branches, but rarely very long, up to 28 cm with secondary branches on lower primary ones.	*E. crus-galli* var. *austro-japonensis*
24.	Spikelets regularly arranged in rows. First glume regularly half the length of the spikelet. Caryopses whitish. Long bristles mostly absent from main axis and branches of inflorescence, occasionally a few scattered along the branches and clustered at nodes.	*E. colona*
24.	Spikelets irregularly arranged. First glume about 0.33 length of spikelet. Caryopses brownish. Long bristles along main axis and branches of inflorescence present or absent.	*E. crus-galli* var. *praticola*

B. Perennials

All perennial species have spikelets 3 mm or more long. Ligular bristles are always present and obvious, especially in the lower leaves. The lower floret is often staminate. Plants may have long creeping rhizomes and/or stolons and spongy floating stems. Sometimes the rhizomes are much shortened and thickened.

1.	Spikelets awnless or with short awns or long cusps. Spikelets crowded, very finely pubescent or for the most part glabrous, with short bristles and short awns or long cusps. Inflorescence often more than 40 cm long. Secondary branches often closely appressed to primary branches of inflorescence. Plant often up to 4 m tall with stout culms.	*E. pyramidalis*
1.	Spikelets awned, awns often long.	2.
2.	Spikelets elliptical or lanceolate, up to 5 mm long with bristles up to 1 mm long and with long, narrow lower glumes. Floating, often with long culms.	*E. stagnina*
2.	Spikelets awned, 3–4 mm long.	3.
3.	Spikelets lanceolate, 3.5–4 mm long, finely pubescent. Awns up to 15 mm long. Racemes up to 90 mm long. Culms stout, up to 3.6 m tall. Leaves up to 20 mm or more broad. Nodes and leaf sheaths glabrous. Ligular bristles obvious on all leaves.	*E. polystachya*
3.	Spikelets broadly ovate, 3–4 mm long with bristles 0.5 mm long. Awns up to 18 mm long, whitish. Panicles sometimes one-sided. Racemes 20–50 mm long. Culms generally less than 1 m. Leave often with transverse purplish bands. Ligular bristles often not on upper leaves.	*E. picta*

Notes on selected taxa

E. crus-galli var. *hispidula*

I believe that this is the appropriate name to use for *E. crus-galli* with non-pyramidal panicles, ovate-elliptical spikelets, usually prominently awned, common in sub-tropical areas and extending to Japan and southern China. There has been disagreement about the nature of *Panicum hispidulum* Retz . on which the name *E. crus-galli* var. *hispidula* is based. Ohwi (1962), who showed a picture of the Retzius specimen collected in India, believed it did not fit features of *tainubie* (now known as *E. oryzicola*). The density of its spikelets, short inflorescence branches and the long fine awns can be fitted easily to occasional specimens from wet places in Japan.

E. crus-galli* var. *persistens

This was originally described by Diao (1988) as *E. persistentia* and later as *E. crus-galli* var. *persistentia* Diao (1990). It's very short lower glume is unusual in *Echinochloa*.

E. mentiens and E. trullata

These are new species from India which are to be described in the online publication *Telopea* in 2017. *E. mentiens* was first collected in Karnataka in the 1850s and rediscovered on my field trip with Father Saldanha from St Joseph's College, Bangalore, after the APWSS Conference in 1981. Dr. Vickery and I noted an unusual *Echinochloa* among specimens from Kew, which we called the "Assam form". At the APWSS Conference at Hyderabad in 2015 Dr. Iswar Barua from Assam Agricultural University showed me specimens, which reminded me of the "Assam form". These, in turn, stimulated me to describe it for publication as *E. trullata.*

E. picta

Yamaguchi (2007), in his treatment of a hidden variety of barnyard grass (*E. crus-galli* var. *riukiuensis*), reproduced a photograph (Plate 2 in his paper) showing plants with distant racemes, whitish awns and one-sided panicles, which made me think immediately of *E. picta.* It would not surprise me to find *E. picta* in the far southern Ryukyu Islands. I have collected it in the far north of Luzon in the Philippines.

E. polystachya

My *E. praestans* has been relegated to a synonym of *E. polystachya*(Simon *et al*., 2009). I had previously followed South American treatments, which considered *E. polystachya* and *E. spectabilis* Nees both as varieties of *E. polystachya*. I now believe they are separate species.

Conclusion

It is to be hoped that readers will have the opportunity to test this key and to report any deficiencies. My hope is that someday more use will be made of the collections of *Echinochloa* in the National Herbarium of New South Wales, which now includes all of the species originally housed in the Faculty of Agriculture at the University of Sydney.

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Biologically-based methods of weed management: The next 50 years

Raghavan Charudattan[39]

Abstract

In the coming decades, weed management methods are bound to be influenced by newer scientific and technological advances from several fronts. Rapid changes will ensue from the use of various forms of microprocessor-based technologies in weed control and crop production and from molecular-genetic methods in herbicide discovery and crop improvement. The present generation of younger scientists of the Asian-Pacific Weed Science Society will witness these changes and find themselves making key advances in Weed Science. They will also set the overall scientific philosophy of managing weeds not only to answer the call from the agriculture sector but also to ensure the overall safety and health of people and the environment.

To this end, I beckon this generation to make a concerted effort to develop and incorporate biologically-based methods as a key component. Bio-based methods have been a practical, but only a relatively minor component of overall weed management tactics, in the past 50 years. Now, there is a strong case to be made for utilizing the emerging biotechnological breakthroughs, such as gene silencing and gene editing to improve and incorporate biologically based methods as a mainstream solution to global weed problems.

Introduction

The theme of this Golden Jubilee Anniversary Conference of the Asian-Pacific Weed Science Society (APWSS) is "*Weed Science for People, Agriculture, and Nature*". To realize the spirit of this theme, today's younger generation of APWSS members should be in a position to research, develop, and deliver weed management principles and practices that address not only the needs of the agriculture sector, but also the public's expectations of safety and health of people and nature.

As a specialist in biological control of weeds, and as a passionate advocate of the use of a broad array of biologically-based weed management methods, I offer here my views, shaped by the past, on the role of bio-based methods in meeting the weed management challenges in the Asian Pacific region, in the next half a century. My career in Weed Science started in 1973 when I was hired by the University of Florida's Department of Plant Pathology to study the use of plant pathogens to control Water hyacinth (*Eichhornia crassipes* [Mart.] Solms) and hydrilla (*Hydrilla verticillata* [L.f.] Royle), two of the most difficult, expensive to control, and environmentally damaging aquatic weeds in the South-eastern United States, at that time. In the following (nearly) half-century, considerable scientific and technological efforts were made around the world, including in my laboratory, to develop and offer microbial biocontrol agents for weed management (Bailey, 2014; Boyetchko *et al*., 2002; Bruckart and Hasan, 1991; Charudattan, 2015; Morin, 2015; Morris *et al*., 1999; Parker, 1991; Watson, 1991).

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Concurrently, entomologists discovered, tested, and provided safe and effective insects as biocontrol agents to manage several invasive weeds (Julien and White, 1997; Cullen *et al*., 2011) in different continents. Also, during this period, integrated weed management systems (combining tillage, no-till, crop rotation, crop spacing, mulching, and others with herbicides) came to be widely adopted in crops, grown on a small-or larger-scale, as a standard practice (see Harker and O'Donovan, 2013). Yet, herbicides remained the single dominant weed control tool worldwide. Others, including biologically-based methods, played only a small or insignificant role. Mirroring this fact, weed scientists in the world published more papers dealing with chemical control compared to other methods. Here, I will attempt to show the relative emphasis the different weed-control methods have received up to now and make a pitch for a greater role for biologically based methods in the next 50 Years. I will also venture to predict some likely changes in weed management methods, including chemical control.

To begin with, to assess the relative emphasis on different weed management methods in the past 50 years, I tallied the scientific papers published in three leading Weed Science journals along with papers from the APWSS conference proceedings, and all titles of presentations (talks and posters) from the recently held 7th International Weed Science Congress (IWSC). My premise was that we, the scientists, tend to publish in our chosen area(s) of scientific interest, job assignment, or clientele needs. Hence, the scientific papers, published or presented in a conference, can be a means to assess the relative roles of different weed management methods in use. Accordingly, I assigned the publications from the above-mentioned sources to Chemical, Mechanical, Cultural, Biological, and Integrated categories. Papers that dealt with studies on weed biology, ecology, molecular biology, and physiology were assigned to Biological-Ecological-Molecular-Physiological category. Papers that expressed opinions or commentaries or described weed problems without experimental data, historical accounts, and keynote addresses were placed in the Perspectives category.

The sources of my survey were chosen for the following reasons. The three international weed science journals, namely Weed Science and Weed Technology, published by the Weed Science Society of America, and Weed research, published by John Wiley & Sons, tend to emphasize works from the Western countries, while the APWSS proceedings incline to represent the Asian-Pacific region. To gain an international focus and recent data, the Proceedings of the 7th IWSC held in 2016 in Prague, Czech Republic, was reviewed. To explain further, the Chemical category included papers that dealt with chemical herbicide(s) (their application, efficacy, physiological effects, and social-economic-ecological aspects). Likewise, papers that dealt with mechanical (tillage, physical removal, mowing) and cultural (burning, cover crops, crop density/spacing, crop rotation, intercropping, mulching, solarization) control were counted respectively under separate categories. The Biological category included papers on biological control using animals, birds, fish, insects, plant pathogens, and microbial biochemical herbicides (the latter two referred to as bio-herbicides in some contexts). The Integrated category included papers that clearly had integration of different methods and tools as the main objective (biological-chemical, cultural-chemical, mechanical-chemical, etc.; chemical-chemical integration was under the Chemical category as was biological-biological integration that was under the Biological category, and similar).

I examined the three journals and the APWSS proceedings every 10th year starting with 1973, the year I began my Weed Science career (except Weed Technology which was first published in 1987). In the APWSS proceedings, only full papers were counted, not posters. The results gave me a snapshot, not an in-depth analysis, of the different methods of weed control described or promoted in the presentations. I used the data (summarized in Figure 1) as the analog of the extent of use of these methods in practical weed management.

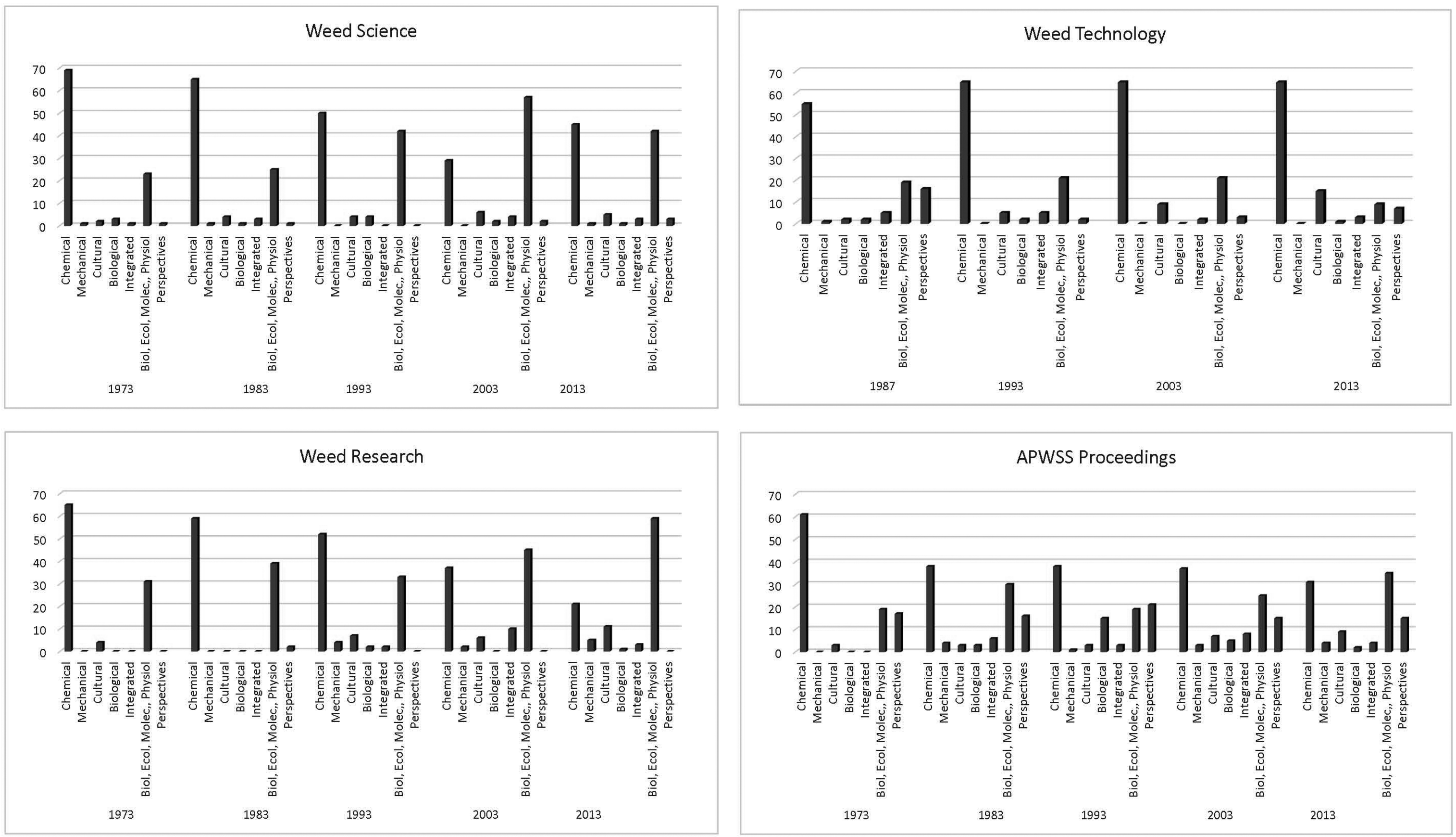

Figure 1. Percentage of papers published over five decades in three international scientific journals and the APWSS proceedings, grouped under seven different categories. The data indicate the predominance of chemical control over other methods of control and a gradual shift towards studies in weed biology, ecology, molecular biology, and physiology during the 50 years examined. Biologically based methods along with cultural and integrated controls have played only a minor role. Likewise, mechanical control has not had a significant role in weed management. See text for descriptions of categories and method of data analysis.

Chemical control was the single predominant method of control in the past years; the data from Weed Technology clearly illustrated this point. The general lack of variation in the Weed Technology data over time was not seen in the other two journals or the APWSS proceedings; all revealed a noteworthy change over time. The journals devoted to "science" (Weed Science) and "research" (weed research) showed an increasing emphasis on studies on weed biology, ecology, molecular biology, and physiology, which was clearly seen in weed research going from 1973 to 2013. This was a notable shift from chemical control, and not from mechanical, cultural, biological, and integrated control methods, the interest in which generally remained unchanged.

Interestingly, the data from the APWSS proceedings revealed a similar pattern to those of Weed Science and Weed research in that there was a gradual shift from the predominance of chemical control in 1973 to increasing emphasis on weed biology, ecology, molecular biology, and physiology as the years progressed.

Perhaps this change in emphasis reflects the realization among scientists that Weed Science as a discipline needs more basic studies to understand and address the complexities of ever-shifting and newly emerging weed problems rather than merely studying and reporting on chemical herbicides. Also, the real, exhilarating "science" behind herbicides lies, in my view, in the discovery of active ingredients, the discovery of target sites, the mode and mechanism of action, and the physiological responses of the weed. These gratifying studies are conducted typically in industrial laboratories long before a product reaches the market.

So, it is understandable if scientists in academia and public research institutions tend to move towards a more stimulating, scientific area than to engage in routine testing and validation of the performance or lack thereof of chemicals. In addition, the public's demand for food free of harmful chemicals and environmental safety of pesticides may have impelled the shift towards basic studies. Still, the above comments notwithstanding, nothing should be taken away from the importance of herbicides as they have helped to prevent economic losses due to weeds and assured high crop yields worldwide since the early 1950s.

In comparison with chemical control, publications on mechanical, cultural, biological, and integrated weed management methods were far fewer. None of these methods, despite their applicability and desirability to certain crops and weed-control situations, supplanted chemical herbicides, either individually or collectively. However, it should be noted that in the case of mechanical/cultural controls, Figure 1 may not tell the full story, as some mechanical tools and cultural practices (tillers, bedding and planting tools, plastic cover, and prior rotational crops) might have been used for weeding, but not mentioned in the paper titles. Likewise, integrated control might not have been a part of the title, although certain levels of integration (crop rotation, crop spacing, and mechanical post-plant weeding) might have been an essential or routine part of the studies.

Based on my experience, biological control appears to be correctly represented in Figure 1 for its relative role. Nonetheless, I am aware of several works of weed biocontrol with insects and some with fish (grass carp) that were published in entomology journals and others rather than in the Weed Science journals. Had they all appeared in the publications I surveyed, biocontrol might have ranked a clear third among the methods. Yet the fact remains that biocontrol has played a small role for the following reasons: First, biocontrol with insects is suitable for invasive, environmental weeds but not for agricultural weeds; invasive weeds are a few compared to the diversity of weeds and weed problems in crops, rangelands, rights-of-way, and other situations. Second, most, but not all, registered bio-herbicides were labelled to control a single weed and therefore, played a small role, compared to chemical herbicides that typically have been labelled to control several weeds.

Among the titles from the 7th IWSC (Table 1), chemical control came first with 38%; followed by biological, ecological, molecular, and physiological studies with 20%. Titles on mechanical, cultural, biological, integrated controls, and perspectives were less than 10% (2% to 9%). Since numerous titles dealt with weed resistance to herbicides, I tallied these titles under Resistance as a subset of Chemical.

Of the 38% of the titles related to chemical control, 41% dealt with the development of weed resistance to herbicides and resistance-related problems. The emphasis on weed resistance indicates the curiosity and desire on the part of the scientist to understand the biological, genetic, molecular, and physiological basis of resistance, in addition to the urgent need for dealing with this problem. Thus, studies on weed resistance now serve as a surrogate and a cohort of basic studies on weed biology, ecology, molecular biology, and physiology that weed scientists had already started emphasizing. Development of herbicide resistance in weeds is a direct consequence of our over-reliance on herbicides, particularly on those with highly target-specific mechanisms of action. Thus, there will be opportunities to explore diversification of weed control strategy by using bio-based methods, as a part of the integrated weed management systems (see below).

Table 1: Titles of presentations from the 7th International Weed Science Congress, 2016, Prague, Czech Republic, sorted by Weed Control subject category[a]

Chemical[b]		Mechanical	Cultural	Biological	Integrated	Biol, Ecol, Molec, Physiol[a]	Perspectives	Total
Chemical	Resistance							
38%	41%[c] (16%[d])	2%	9%	9%	5%	29%	8%	100%

[a] See text for details of categories.

[b] All titles in the Chemical Control category were counted and those that dealt with weed resistance to chemical herbicides were assigned to the subset of Resistance category.

[c] Titles in the Resistance category as a percentage of the Chemical Control category.

[d] Titles in the Resistance category as a percentage of the total titles.

The Next Fifty Years

What might the future hold? From scientific literature including the APWSS proceedings and by my attending Weed Science meetings around the world, I see the following developments in chemical, mechanical, cultural, and biological controls. My intent here is not to list all likely developments, but rather those that I see as promising new entries or those that are already in use which will continue to gain predominance in coming years. In other words, if I were a young, starting scientist or an early-career scientist, I would pick the following as the likely game-changers in weed management. I believe the younger generation of APWSS members will find in these developments areas of immense possibilities for making research contributions.

Herbicides

Despite recent consolidation of multinational companies in the herbicide business, new herbicide active ingredients will be discovered using conventional search-and-screen methods. In this regard, biochemicals from microbial and other biological (e.g., botanical) sources will continue to provide leads for new active ingredients, synthetic analogs, and site-of-action targets. While the pipeline of new active ingredients and products has currently slowed to a trickle compared to the 1980s, which is attributed largely to the widespread cultivation of glyphosate-tolerant crops, I do wonder how long the herbicide-tolerant (genetically modified organism; GMO) crops will hold their sway before a newer technology or anovel active ingredient supplants them. Meanwhile, the need to incorporate integrated weed management systems (IWMS) in herbicide-tolerant crops is eminently clear, given the extent of existing and emerging herbicide resistance problems around the world. Hence, I believe there will be a concerted effort to apply IWMS in herbicide-tolerant crops, and this area will offer a rich array of scientific topics and weed management models to explore (see Harker and O'Donovan, 2013; Lamichhane *et al*., 2017).

Mechanical Control

Increasingly weed management will be carried out by computerized "smart" machines with electronic sensors to distinguish between a crop plant and a weed, robotic weeders, and precision sprayers of various capabilities. High-tech machines that prepare fields and densely plant crops to promote shading and competition to minimize weed infestation will become a standard practice. Drone-assisted mapping of weed distribution to help target herbicide application will also be widely used. Hence, mechanical control is poised to become a key method of weed management within the next two or three decades (see Fennimore *et al*., 2016).

Cultural Control

Cultural practices, such as tilling and preparing soil for planting and the use of cover crops, crop rotation, intercropping, and post-emergent weeding between rows of crops are all a routine part of crop production. These methods will continue to be used with improved tools, techniques, and precision. Mulches of various kinds are used in the production of vegetables, berries, and other high-value crops.

We can expect to see newer materials as mulches. My research team has explored the use of organic mulches infused with weed-suppressive microorganisms to manage weeds (Morales-Payan *et al*., 2008; Shabana *et al*., 2008). Although our results are preliminary, the approach of delivering weed-suppressive agents in mulches deserves further study and development. In addition to weed-suppression, mulches can also be used to deliver agents suppressive to root-diseases and parasitic nematodes and for site-specific dispersal of allelopathic/phytotoxic weed-suppressive compounds (Putnam and Defrank, 1983).

Another exciting area is the anaerobic soil disinfestation (biological soil disinfestation), a pre-plant method that has been shown to reduce or eliminate soil-borne pathogens, parasitic nematodes, and weeds without eliminating soil microorganisms but in fact promoting microbial recolonization. The method involves the creation of anaerobic conditions by incorporating materials rich in decomposable carbon (organic amendments, molasses) in soil, compacting and saturating the soil with water, and covering the area with plastic for a several days. The resulting anaerobic condition causes the suppression/elimination of pests and weeds during anaerobic digestion of the organic material, thus preparing the soil for planting. This method is a practical alternative to the use of methyl bromide for soil fumigation, and it provides the opportunity to integrate various types of organic of amendments, organic and plastic mulches, and waste, or surplus products from food industry to serve as carbon sources (see Di Gioia *et al*., 2016; Lamers *et al*., 2013; Momma *et al*., 2013; Rosskopf *et al*., 2015; Shrestha *et al*., 2014).

Also anticipated is the development of crops that better compete with weeds (Andrew *et al*., 2015) and crops, which are genetically modified to produce weed-suppressive allelochemicals (Duke, 2003).

Bio-based Control

Biological control by using phytophagous arthropods (insects and mites), plant pathogens (fungi, bacteria, viruses, and nematodes), fish (grass carp), birds (geese), and other animals (sheep) will remain an option for a foreseeable future, albeit for certain specific weed control needs. Classical biocontrol, defined as the use of imported agents to control exotic invasive weeds, principally by using insects and pathogens, has provided some spectacular, highly cost-effective, and singular means of control of invasive weeds (Clewley *et al*., 2012; Morin, 2015; Winston *et al*., 2014; Wood, 2012). It is anticipated that interest in using classical biocontrol will continue because of its advantages in lower cost of discovery, development, and use than chemical herbicides, long-term recurring benefits, effectiveness, and environmental friendliness.

Historically, classical biocontrol has been supported by public funds provided to university and governmental or quasi-governmental research establishments. In the latter category, the Centre for Agriculture and Bioscience International (CABI), previously the Commonwealth Institute of Biological Control (CIBC)-United Kingdom, with research centers in several host countries, Commonwealth Scientific and Industrial Research Organization (CSIRO) - Australia, Land care Research (Manaaki Whenua) - New Zealand, Plant Protection Research Institute (PPRI) - South Africa, and the U.S Department of Agriculture (USDA) Agricultural Research Service (ARS) and Forest Service (FS), to name a few, have contributed enormously by supporting research, testing, release of agents, and post-release assessment of success.

Collectively, scientists at these research institutions and several universities have developed and founded methods and protocols for classical biological control that are used worldwide. Looking forward, it is essential that public support for classical biocontrol be continued and younger scientists join the ranks to replace the senior and soon-to-retire scientists so that this field of endeavor may progress uninterrupted.

As stated above, bio-herbicides, namely, the use of plant pathogens as weed-specific herbicides and microbial metabolites as bio-rational herbicides, have played only a minor role thus far (Charudattan, 2015; Harding and Raizada, 2015). To have wider acceptance and relevance in the coming decades, the future microbial herbicides should be capable of controlling multiple rather than single weed targets or weeds of worldwide importance (e.g., Water hyacinth, nutsedge [*Cyperus rotundus* L. and *C. esculentus* L.]. They should possess stable, high levels of efficacy in the field.

In addition, in the coming decades, understanding how certain pathogens kill plant cells, tissues, or entire plants should be a major goal. To this end, work must continue to find suitable weed-pathogen pairs to serve as study models. For example, host-pathogen systems where pathogenicity is controlled by a gene-for-gene interaction could be used to study how systemic necrosis leading to plant death is triggered and cascaded through the plant. With the help of newer, molecular biological methods, bio-herbicides can be tailored to have performance and commercial features that make them readily accepted as a weed management tool.

Biochemical herbicides derived from microbial and plant sources that fall under the bio-herbicide definition of the U.S. Environmental Protection Agency (EPA) will be important in weed management in the coming decades (see Dayan and Duke, 2014; Marrone, 1999).

Application of molecular-genetic methods based on gene silencing and Clustered Regularly Interspaced Short Palindromic Repeats (CRISPR) and CRISPR-associated protein-9 nuclease (Cas9) (CRISPR/Cas9) are likely to help, respectively, to regulate (silence/turn-on) the expression of desired/undesired genes involved in the biosynthesis of herbicidal metabolites and to carry out targeted gene editing to impart desirable traits in microorganisms used to produce herbicidal metabolites. The same two methods could be used to design bio-herbicidal pathogens to possess high degrees of efficacy, consistency, shelf-life, etc. These newer molecular-genetic approaches will be more readily accepted and used if they are considered as biologically based methods and regulated as such rather than as GMOs.

Developments in molecular biology and in-situ detection technologies also make it possible to study the microbial milieu, or the microbiome, surrounding plants in far greater detail and precision than before. We now have the capability to search for unique microorganisms that could not have been found in the past. The vast and diverse microbial community that makes up the microbiome is a storehouse of microbial species. For example, microbes that produce novel herbicidal metabolites, seed germination inhibitors, and perhaps even new plant-associated microbes could be discovered. An understanding of microbial competition and survival in populations may also yield clues to improve the survival of introduced biocontrol agents under harsh or unpredictable physical conditions (see Sébastien *et al*., 2015).

Research is already underway on several weed-suppressive bacteria discovered by conventional methods. For example, it has been shown that the soil bacterium *Pseudomonas fluorescens* (Flügge) Migula, strain BRG100, is effective in suppressing green foxtail (*Setaria viridis* (L.) Beauv.), when applied pre-emergence. BRG100 has broad-spectrum activity and can inhibit other annual grass weeds as well. It also has antifungal activity and therefore may be used to control fungal plant diseases. It produces two biologically active compounds, pseudophomin A and B, of which pseudophomin B has higher antifungal activity against plant pathogens than pseudophomin A. However, the latter inhibits root germination of green foxtail more strongly than pseudophomin B. Other unidentified compounds are also produced that work synergistically (Caldwell *et al*., 2012; Pedras *et al*., 2003).

Finally, to advance research, development, and integration of bio-based methods, policy and executive commitments should be made at public (universities, governmental research organizations) and private (companies) entities. The present level of investment of human and other resources in bio-based methods is not sufficient and should be increased worldwide with a coordinated global framework, with appropriate laws and regulations, to encourage development and use of bio-based methods. Overall, a proactive stance is needed.

Epilogue

Whether you are embarking on a Weed Science career, or an early-career scientist, you are likely to engage in Weed Science and weed management in ways that are different from those of your predecessors. You will have a choice to work on a range of novel, scientifically challenging, interesting, and rewarding aspects of weed science and weed control methods. Choose those that offer emotional satisfaction to you – the scientist, the academic, the professional. Don’t settle for the mundane.

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Ethics, Agriculture, and the Environment

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Whether one lives in a developed or developing country and whether one is rich or poor, male or female, educated or not, we live in or are moving toward a post-industrial, information age society. But we do not and no one ever will live in a post-agricultural society. We are fortunate to live in an era of scientific achievement and technological progress unequalled in human history, which has created the good life many of us enjoy and some of the problems from which we suffer. The achievements include:

- Waking up this morning to music from your cell phone.
- Preparing breakfast in your microwave as you review the news on your computer, which gives you nearly instant access to information that is orders of magnitude greater than the resources of any of the world's libraries.
- Medical advances that cure what used to kill or cripple.
- Immunization to prevent childhood diseases.
- Elimination of smallpox and possibly polio in the near future.
- Vastly improved detection and control of some diseases.
- Travel at speeds and convenience unknown to our grandparents, across oceans and mountains that were once formidable barriers.
- And finally, for many, abundant food.

The problems include climate change, global warming, and pollution of all forms, social inequality, environmental degradation, and soil erosion. Many citizens of developed countries know and benefit from the achievements and are concerned about the problems science and technology have wrought.

We live in a world where progress, which is frequently equated with growth, is expected and generally regarded as good. Many want more of the good things of life and expect the future to be bigger, better and arrive faster. We exult in the good in lament the bad. So many aspects of our life change faster than we are able to keep up. We may not always know our destination, but we are going there in a hurry. We are beneficiaries and believers in the efficacy of technology. Technology promises to solve the problems of society, agriculture, and our extractive, industrial economy. In agriculture, where I have spent my career, we believe that development and use of more and more sophisticated, high energy, advanced technology is always good and more is better. The agricultural problems caused by the unintended consequences of previous technological solutions will, of course, be solved by more high-tech solutions - by improved technology.

I do not mean or intend to imply that we should abandon science and its resultant technology. I do assert that we need to "abandon the narcissistic illusion that we can control our interventions in an infinitely complex world" (Jensen 2016). We humans, Earth's dominant species, are not just figures in the landscape – we are shapers of the landscape (Bronowski 1973, p. 19). We should think about the consequences of how we shape the landscape. Although we may not always know what we are doing, we should consider

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what we may be undoing. A bit of intellectual humility might compel us to be more careful with our tinkering (Jensen). We need to cultivate in ourselves and our students intellectual humility that helps us be more careful with our science and our technology and leads to thought about the moral dimension of what we do and undo.

With that brief introduction, what I want to do is ask and leave you with two questions. How do you decide, what you choose to do is the right thing to do? How do you know what is the right thing to do (Zimdahl 2012)? We all acquire a sense of what is right and wrong, which is often unexamined and not supported by careful reasoning. A guide toward helping decide what one ought to do is found in our ethical principles, which we all have. They are guides, not answers based on societal principles that help us decide and may govern what is right and wrong. Understanding and using ethical principles, our invisible guides, is often complicated by confusion over what ethics is and is not. Ethics is not four things.

1. It is not just a set of prohibitions-do not rules-that are concerned with sexual behavior or religion. In my tradition, we all grow up with rules that say do not kill, steal or lie. I am sure other cultures have the same kinds of do not rules.
2. Ethics is not an ideal system that is noble in theory, but useless in practice. The reverse is true. An ethical judgment that is no good in practice has serious theoretical faults.
3. Ethical principles are not relative to time, culture, society or parents. They are influenced by those things, but are not necessarily determined by them.
4. Ethics is also not just subjective. Many people think that an ethical act is always deemed to be right or wrong based on one's feelings and nothing more. That's wrong. Such an attitude means that there is no such thing as an objective right or wrong. When I say slavery, Nazi Germany, female genital mutilation are wrong, is this merely my subjective view, that I, at this time and place in society, say they are wrong? No, there is widespread, perhaps universal agreement that these things are wrong and the reasons provided across cultures will be similar.

I ask again how do you decide what is the right thing to do?

Critical thinking is required. It is an intellectually disciplined process of conceptualizing, analyzing, and evaluating information gathered from observation and experience and using it as a guide to belief and action. Critical thinking employs universal intellectual values: clarity, accuracy, relevance, sound evidence, good reasons, and fairness. It is difficult.

We all use ethical terms every day - good - bad, immoral - moral, right - wrong, just - unjust. We have personal ethics - guides to our daily behavior related to sex, voting, church, and charity. We are all subject to social ethical expectations related to murder, torture, pornography, civil rights, and children. We have professional ethics that include not fabricating the data, giving proper credit, being honest, including results opposed to a particular hypothesis, not plagiarizing, and disclosing conflicts of interest. We have goals. We want to help create a world that is just, peaceful, generally prosperous, democratic, free of prejudice of all kinds, and humane. These worthy goals are not our exclusive responsibility. Achieving them is a responsibility shared with all segments of society.

Ethical standards gone wrong are a prelude to sweat shops, mistreatment of women, concentration camps, child labor, or torture. Ethical standards change. Examples from my culture include business hours, smoking, women's rights, and treatment of animals and the environment.

All academic disciplines have an ethical component. The truest test of the moral condition of any scientific or other discipline, indeed of one's life, is a willingness to examine its moral condition. In agriculture, we have not examined our ethical base or the reasons for it. In natural resources and environmental study examination has occurred because public pressure has demanded it.

Philosophers study ethics. They don't tell us what is right and wrong. They show us how to think about what is right and wrong. Change occurs because an unexamined principle, once articulated and brought into the light for examination, is found lacking and abandoned in favor of other, revised thinking. My culture and perhaps yours provides several examples of change: civil rights, women's rights, environmental rights, animal rights. But there's been no comparable change and little critical thinking in agriculture.

Scientists claim that in the scientific realm there are answers which can be defined mathematically, are publicly verifiable, literal, definitive, precise, and falsifiable. In contrast is common to believe that ethical positions are purely subjective - they are only personal opinions that lack a rational justification. That is false. Ethical claims are supported by careful logical reasoning. The normative, descriptive language speaks of what is most important and why it is or ought to be valued. Moral/ethical reasoning reflects a long, distinguished history of rational public discourse.

There is a dominant ethical position that characterizes agriculture. It is productionism. It is the central norm, indeed often the only norm, of agriculture. The moral imperative is to produce food and fiber to benefit all humanity. Those involved in agriculture whether they are producers, suppliers, or researchers, and regardless of their employer should ask and debate if production is a sufficient criterion for judging all agricultural activities. Does it justify everything?

What about other responsibilities: achieving sustainable production practices, decreasing pollution, eliminating soil erosion, eliminating harm to other plant and animal species, ending habitat destruction, and ending water pollution and mining water for irrigating agricultural crops. All segments of the agricultural enterprise ought to work toward accomplishing these equally worthy, morally good goals.

Agricultural scientists have assumed that as long their research and the resultant technology increased food production and availability, they and the end users were somehow exempt from negotiating and re-negotiating the moral bargain that is the foundation of the modern democratic state (Thompson, 1989). It is unquestionably a moral good to feed people; agriculture does that. Therefore, it is assumed that anyone who questions agriculture's morality or the results of its technology simply doesn't understand the importance of what is done. It is assumed that researchers are technically capable and that the good results of technology make them morally correct. We are obliged to question that assumption.

The American author Wendell Berry (1999) has done so. Berry reminds us "We have lived by the assumption that what was good for us would be good for the world. We have been wrong. For I do not doubt that it is only on the condition of humility and reverence before the world that our species will be able to remain in it." It is perhaps a human trait - we do not want to question our assumptions, we want to use them.

The public is concerned about pesticides in soil, water and food, cruelty to animals, biotech/GMOs, corporate agriculture, mining of water, loss of small farms and rural communities, loss of genetic diversity, pollution by animal factory wastes, exploitation of and cruelty to migrant labor, and soil erosion. These are not concerns of a radical fringe of society. They are societal concerns and therefore an agriculture based solely on production has an ethical challenge.

Agriculture is the essential human activity. It is the largest, most widespread, and most important human interaction with the environment. One might ask if the essence of environmental ethics is protecting ecosystems from agriculture. Because agriculture has well-defined, unavoidable negative environmental consequences, it is my view that agriculture must develop and have a firm ethical foundation. It is not just about results. We should not assume that because we believe in what they do, and the result has been mostly good – more people are fed than ever before – that those who practice and support agriculture automatically have societal acceptability. I offer three points about agriculture:

1. Those engaged in agriculture are certain about the moral correctness, the goodness, of their activity.
2. The basis of that moral certainty (the supporting reasons) is not obvious to those who have it.
3. In fact, agriculture's moral certainty is potentially harmful because it is unexamined by most of its practitioners.

Moral certainty and lack of moral debate inhibit discussion about what agriculture ought to do or be. Debate will reveal the foundational moral theories. We will find guides not absolute rules which will represent the, often invisible, foundation on which our actions rest. Exploration of the moral certainty posited for agriculture will not reveal a single guiding principle that will solve all agricultural dilemmas. It will reveal several principles that will be useful as we explore alternative production technologies.

The story of the productivity and success of modern agriculture may be the greatest story never told (Sidey 1998). Few if any other segments of the world's scientific-technological enterprise have such an impressive record. Western agriculture is a productive marvel and is envied by many other societies where hunger rather than abundance dominates. Science and technology have created steady yield increases [development of higher yielding cultivars, synthetic fertilizers, better soil management, mechanization, and improved pest control]. Without the yield increases that have occurred since 1960, the world would now require an additional 10 to 12 million square miles (roughly the land area of the U.S., the European Union countries and Brazil combined) for producers to achieve present levels of food production (Avery 1977). Modern high yield agriculture may not be one of the world's problems but rather the solution to providing sufficient food for all, sufficient land for wildlife, and protecting the environment. Agricultural producers are proud of these achievements. As agriculture's productive capabilities have been enhanced by science based discoveries it is not surprising that the endless pursuit of production has conflicted with other societal values (Thompson 1989).

Agricultural technology has always exposed people to risk. In the past most of the risk was borne by users of the technology. Now many risks of agricultural technology are borne by others. Technology developers, sellers, regulators, and users, in their moral certainty, have not secured or even considered how to secure the public's consent to use technology that exposes people to involuntary risk. Agricultural producers and those who support them with technology have been seduced into thinking that, so long as they increased food availability, they were exempt from seeking societal approval for employing the technology that modern agriculture requires, which simultaneously exposes people to involuntary risks. That is not how modern democracies are supposed to work. The result is that citizens of democratic societies have become reluctant to entrust their water, their diets, or their natural resources blindly into the hands of farmers, agribusiness firms, and agricultural scientists.

Agricultural people must begin to participate in a dialog that leads to social consensus about risks, and they must be willing to contribute the time and resources needed to understand the positions of their fellow citizens. For most non-agricultural segments of society, these are not new demands. For agriculture they are. Agriculturalists have been so certain of the moral correctness of their pursuit of increased production that they have failed to listen to and understand the positions of other interest groups (e.g., environmental groups, organic practitioners). Agriculturalists have not articulated any value position other than the value of production and have not offered reasons why production ought to retain its primacy.

What is the primary agricultural problem? Is it production? Of course it is. However, food distribution, waste (Institution 2013), and poverty must be considered. Production of abundant food and fiber must remain a goal of agriculture. But, because we live in a morally pluralistic world, we are compelled to ask if more production is the only right answer to the many dilemmas agriculture faces.

Agriculture's practitioners should discuss and debate what other goals ought to be considered by agriculture and when and why one or more of them ought to take precedence over production. For example: sustainable, environmentally safe production that meets human needs, and contributes to a just social order may be of greater moral importance than profitable production. This is not the dominant agricultural view. Sustainability is regarded by those in agriculture as primarily a production and secondarily an environmental goal. In agriculture, to sustain usually means protecting the productive resource (soil, water, gene pools) to maintain production. Others argue the productive resource is important, but ranks below sustaining environmental quality. Few agricultural voices speak of a just social order. There is no inherent objection to achieving a just social order, but it is not what agriculture does.

The view of sustainability depends on what one wants to sustain. The debate goes to the heart of what agriculture ought to be. Agriculture has a major responsibility because it is so widespread and has the potential to care for or harm so much land. This is a different view from protecting only the productive ability of land. Land is not simply a productive resource. It is the basis of life. Without the land there will be no agriculture, so land must be regarded as something more than other productive resources (e.g., fertilizer, machines, irrigation water, pesticides, or seed). To harm or destroy the land is to destroy something essential to life, and that certainly raises a moral question.

The challenge of social and environmental goals for agriculture is that they involve values. It is generally not recognized in agricultural science that values are not external to the science and technology but its basis. Scientists know they are responsible for the scientific integrity of their work and for its intellectual contribution. They do not as readily assume responsibility for the moral aspects of their work. All of science and all of agricultural science is involved in moral/value questions. Science is not value-free, it is value-laden. The research and teaching we do involves assumptions and a view of a future we expect, desire, or fear. As we consider agriculture's ethical foundation, there will be conflicting interests, incompatible analyses based on different views of the nature of the problem, rising material expectations, and different views of sustainability. It is unusual to find anyone against sustainability. It is equally clear that there are many views of what ought to be sustained and how to achieve sustainability.

I conclude that while agricultural scientists are ethical in the conduct of their science (they don't cheat, don't fake the data, give proper credit, etc) and in their personal lives (they earn their wages, take care of family, respect others, are responsible for their actions, etc..), they do not extend ethics into their work. Agricultural scientists are reluctant revolutionaries that Ruttan (1997) identified, but also realists. Realists run agricultural research and the world; idealists do not. Idealists attend academic conferences and write thoughtful articles from the side-lines (Kaplan, 1999). The action is elsewhere. The reality may be publish or perish in academia, but it is produce profitably or perish in the real agricultural world.

Realism rules, and philosophical and ethical correctness are not necessary for useful work in agriculture or any other scientific discipline. I find that true, but I want more.

I want us to accept the difficult task of analyzing agriculture and its results. We must strive for an analysis of what it is about our agriculture and our society that limits our aspirations and needs modification. The analysis must include departments of agriculture, university departments, scientific societies, research institutions, and commercial organizations that serve and profit from agriculture. We must strive to strengthen those features that are beneficial and change those that are not. We must be sufficiently confident to study ourselves and our institutions and dedicated to the task of modifying both.

To preserve what is best about modern agriculture and to identify the abuses modern technology has wrought on our land, our people and other creatures, and begin to correct them will require many lifetimes of work. Agriculturalists must see agriculture in its many forms – productive, scientific, environmental, economic, social, political, and moral. It is not sufficient to justify all agricultural activities on the basis of increased production. Other criteria, many with a clear moral foundation, must be included.

We live in a post-industrial, information age society, but we do not and no one ever will live in a post-agricultural society. All societies have an agricultural foundation within their borders or elsewhere. Those in agriculture must strive to assure all that the foundation of the largest and most important human interaction with the environment is secure.

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The Future of Weed Science in the Asian-Pacific Region – Some perspectives for the Next 50 Years

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Introduction

Weeds compete with crop plants and reduce the yield through competition for light, soil nutrients and moisture. Generally, the competition among crop plants and weeds is considered to be intense during early phases of crop life (4-6 weeks of germination or transplantation), although the critical competition period varies for different crops. Modern-day farmers use different management methods (mechanical weeding, hand weeding, crop rotation, herbicides) to manage weeds in crops, and their selection mostly depends upon the economics and performance of the individual strategies. Until about the early 1950s, hand weeding was the main method used to control weeds in most crops, but with labor scarcity, increase in labor wages, and unsuitability under some situations, manual methods became gradually less cost-effective and unsuitable. Manual weed control methods dramatically declined with advent of the herbicide era, which began around 1944 with the discovery of auxin herbicides. Herbicide use transformed weed control, particularly in the 1960s decade, especially in 'western' countries that had well developed and mechanized farming systems.

The evolving crop production systems, such as, mechanized farming and conservation tillage systems, despite their progress and popularity, resulted in some problems including control of weeds and other crop pests. Two of the most important concerns were the development of herbicide resistance (Powles and Matthews, 1992) and shifts in weed species spectra (Gressel, 1992). The continuous use of herbicides reduce the weed densities in treated areas, increase the populations of resistant weeds and create opportunities for new weeds to invade in a cropping system. Similarly, when there is a major change in a cropping system, the weed flora will also change; for example, in conservation tillage systems, densities of some annual and perennial weeds increase and require innovative methods to manage them. Likewise, the adoption of direct-seeding technology in place of transplanted rice resulted in changes in the composition of weed flora in many parts of the Asia Pacific region (Rao *et al.,* 2007; Singh *et al.,* 2008; Kumar and Ladha, 2011).

Although weeds are one of the most important factors in loss of yields in food crops in the Asian-Pacific region, management of weeds has not been given the due importance, yet, as compared to insect pests or disease control. Progress has certainly been made in tackling the issue of weed management in the region; however, in the future, increased focus should be on some of the emerging issues, such as, herbicide resistance and weed population changes, and at same time, explore alternate methods of weed management through better understanding the weed biology and ecology and crop-weed interactions.

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More emphasis should be given on development of nonchemical control technologies (e.g. biological control, competitive cultivars) and their integration with chemical control. Current level of investment in Weed Science research funding is scarce as compared to insect pests and diseases, a reasonable funding would be required to develop more knowledge based integrated weed management. In the following sections, we provide some suggestions and discussion with historical perspectives, and future directions on some of these critical areas of importance for Weed Science.

Herbicide Resistance

The evolution of herbicide resistance in weeds is one of the greatest challenges to Weed Science, in recent decades and future years. As another parts of the world, this is a major issue in the Asian-Pacific region as well (Beckie and Tardif, 2012; Heap, 1997, 2014; Powles 2008; Powles *et al.,* 1996). Table 1 provides an overview of number of herbicide resistant weeds in some Asian-Pacific countries (Heap, 2014).

Herbicide resistant weeds in the Asian-Pacific (and other parts of the world) will continue to grow as little or no precautionary measures are adopted, especially in developing countries of the region. In order to plan for Asian-Pacific region for the next 50 years, we may need to adopt a few strategies that are relevant to this region. They include: (1) timely detection of herbicide resistance evolution in weeds and execution of required technological options, (2) cultivation of crops following good agricultural practices, (3) inclusion of crop rotation in the farming plans at a particular farm, (4) rotational use of herbicides, (5) use of herbicides in mixture, and (5) use of integrated weed management option (Beckie, 2006; Délye *et al.,* 2013; Norsworthy *et al.,* 2012).

Table 1: Number of herbicide resistant weeds in Asian-Pacific countries (Adopted from Heap, 2014)

No.	Country	Number of herbicide resistant weeds
1	Australia	62
2	China	34
3	Japan	18
4	Malaysia	17
5	New Zealand	15
6	Iran	11
7	Thailand	5
8	India	3
9	Indonesia	1
10	Taiwan	1

Weed Shifts

The knowledge on the responses of weeds to various production systems is generally limited. Changes in weed species composition and abundance are the consequences of changes in weed management practices and evolving production systems. Any change in agricultural practices in a cropping system may lead to shifts in weed's relative and absolute populations. Certain weeds density reduces while those of others increases in the niche created by a particular management practice or altering agricultural methods. Weed shifts and new weeds emergence was reported in response to selection pressures exerted by the changing cropping systems.

For example, *Amaranthus rudis* Saur become problem only after selective use of herbicides in new cropping systems in the US (Hall *et al.,* 2000). Similarly, weeds are considered to be a major constraint in adoption of conservation tillage systems (Owen, 1998). It has been reported that reduced soil tillage and regular fallows promotes some perennial weeds and even woody plants. The gaps created by declining weeds are readily filled by less abundant weeds, or new comers, as part of ecological succession. Although weed shifts are rapid and remarkable, these could be superficial considering long persistence of seeds of many weeds in soil.

To develop effective weed management strategies, it is essential to understand the relationship of weeds and crops in agricultural systems. For the long-term understanding of weed shifts, large scale field trials, comparing the existing and new crop production systems, are required, at multiple sites (Hall *et al.,* 2000). Maintaining accurate records of weed populations and distribution patterns is an essential part of weed management systems, it provide opportunities for resource conservation. In the future, more resources would be needed to investigate the responses of emerging and evolving weeds to new cropping systems and management practices.

Understanding Weed Biology and Ecology

Weed Science research is primarily focused on weed control (chemical, physical and biological control) while, generally, there has been less attention is paid on basic principles, such as weed ecology and biology. In the last few decades, research on chemical control has received the maximum attention, with limited focus on physical and biological control (Wyse, 1992). To develop appropriate weed management techniques, the most important task of Weed Science is to better understand the weed biology and ecology (Buhler, 1996).

Weed scientists have always known that it is important to understand the weed calendar and the critical time of competition of major crop weeds and to identify the most susceptible life history stages of these weeds to target for control. However, such research has always been secondary to herbicides and their use weed control. The basic research on weed biology has led to a better understanding of the critical period of weed competition, or the threshold period during which the efficient use of control, such as the application of herbicides, hand weeding and biological control etc. would be most beneficial.

The study of spatial and temporal variations in the composition and distribution of weeds in arable fields is a key to develop resource conservation technologies, for instance, 40 – 50% reductions in the usage of herbicides was reported in site specific weed management in some field crops (Gerhards, 2013; Castaldi *et al.,* 2017). If weeds are to be managed spatially in précised manner, accurate sampling methods for mapping of weeds distributions would be required (Rew and Cousens, 2001). Further, a thorough understanding of the biology of the weeds and their interactions with agroecosystems is essential for the development of models used in the site specific weed control technologies.

Weeds are difficult to control for a number of reasons. Some of the important biological characteristics shared by most of weeds include large numbers of seed production, persistence of seeds in soil seed banks, seasonal dormancy, and more than one mode of reproduction (sexual and vegetative). Studies on weed population dynamics are important to understand the abundance of weeds in field and to develop management programs in any cropping system. Without identifying weakness of the problematic weeds, it would be difficult to develop current and new control techniques.

The development of new weed management strategies (especially non-chemical control) will depend upon our sound understanding of the biology and ecology of weeds. Hence, for the effective future weed management in Asian-Pacific region, more resources would be needed for basic research on the biology and ecology of important weeds. Needless to say, if more resources can be channelled towards basic research on the biology and ecology of important weeds, it will lead not only to refining current weed control methods, but also to the development of new control technologies.

Non – Chemical Weed Control

Crop Rotation

In crop rotation, the order of crops is changed over several growing seasons to achieve benefits, such as restoring soil fertility, diminishing pest populations, specific to certain crops, and increasing the usefulness of resources. The ecological impacts and allelopathy are known to suppress weeds in any crop rotation (Narwal, 2000). For example, a comparison of various crop rotation systems for their weed suppressive effect indicated that sorghum (*Sorghum bicolor* L.) - wheat (*Triticum aestivum* L.) rotation had higher weed suppression than other rotations, such as the mung bean [*Vigna radiata* (L.) R. Wilczek]-wheat, rice (*Oryza sativa* L.) - wheat, cotton (*Gossypium hirsutum* L.) - wheat or fallow-wheat (Shahzad *et al.,* 2016).

The rice-wheat rotation is among the major cropping systems of many countries in the Asian region. Narwal (2000) suggested that weeds in the rice-wheat rotation systems of several Asian-Pacific countries could be suppressed by the rotation of other allelopathic crops, such as maize and sorghum, with the major summer crop (rice); and berseem (*Trifolium alexandrinum* L.) and oat (*Avena sativa* L.) with winter crop (wheat). Although crop rotation is considered as a classical weed control strategy, its importance, as a component of integrated weed management in the future has not declined, in the Asian-Pacific region, or in other regions of the world.

Tillage

Tillage is aimed at improving the soil tilth and to suppress weeds (Hussain *et al.,* 2017). During recent times, the urge for growing organic foods and address environmental issues has increased the importance of tillage as a weed control strategy. In the Asian-Pacific region, this technique can be used to manage weeds as a component of integrated weed management in crops having wider rows, such as vegetables, maize, sunflower etc. Intelligent weeders are the ones that can operate within the crop rows (to control weeds) without damaging crop plants. Such weeders may be equipped with sensors to differentiate between the weed and crop plants. Nevertheless, intelligent weeders may be the correct option for crops with narrow rows (Hussain *et al.,* 2017).

Water scarcity in the Asian-Pacific region (and other parts of the world) is likely to increase in the future, resulting in lower water availability for agriculture, particularly for crops with high water requirements, such as rice. Direct-seeded rice (DSR) is regarded as a suitable option for future scenarios under water scarcity. However, weeds are likely to become major problems and will decrease rice productivity ends, unless effective management is undertaken (Jabran and Chauhan, 2015).

Weed control in DSR is difficult compared to the flooded, transplanted rice (TPR), due to the reduced efficacy of herbicides in dry conditions, compared with the saturated soil in flooded rice, and a higher abundance of weeds in DSR than in TPR. Tillage attains greater significance under such situations to achieve effective weed control under DSR (Akbar *et al.,* 2011).

Competitive Cultivars

The role of competitive crop cultivars in suppressing weeds is well-reported in the Asian-Pacific region. For example, in West Bengal, India, green-gram genotypes such as PDM 54, WBM 04-5 and WBM 34-1-1 were found to be competitive against weeds including *Cyperus rotundus* L., *Digitaria sanguinalis* (L.) Scop. and *Croton bonplandianus* Baill. (Duary *et al.,* 2014). Bajwa *et al.,* (2017) reviewed the competitive crop cultivars grown in Australia, including wheat (Heron, Katunga), barley (Baudin, O'Connor, Flagship, Hamelin), and sorghum (Bonus MR, MR Goldrush). Similarly, the weed-competitive cultivars of maize, rice and wheat were reviewed by Ramesh *et al.,* (2017). Rice cultivars: PR-120, Vandana, RR-151-3 IR88633, Prabhat, Kalinga-III, and IR83927 and wheat cultivars: PBW343, WH147, HD2687, and HD 2285 were reported as most competitive against associated weeds (Ramesh *et al.,* 2017). Continuing research on competitive crop cultivars will be an important component of future integrated weed management strategies for any crop.

Cover Crops and Mulches

Cover crops are the ones planted along the major crops to achieve benefits such as protection of soil, conservation of water, enhancing biodiversity and controlling weeds. Mulches comprise of any stuff used to cover the soil surface for protecting it from erosion, increasing water retention and controlling weeds. Some important cover crops may include clovers, pea (*Pisum sativum* L.), hairy vetch (*Vicia villosa* Roth), and cowpea [*Vigna unguiculata* (L.) Walp.], and rye (*Secale cereale* L.). Similarly, both plastic and straw mulches have been utilized in the various agricultural systems. Cover crops and mulches suppress weeds, conserve soil, and augment the retention of moisture in soil (Samedani *et al.,* 2014; Jabran *et al.,*2010a).

Cover crops and mulches are not very popular in the Asian-Pacific region, although crop and weed residues, used as mulches are gaining some increased attention in recent times. Wheat residue (4 t ha^{-1}) (Singh *et al.,* 2007) or rice straw (Devasinghe *et al.,* 2011), used as mulch in rice in India, significantly suppressed weeds (Singh *et al.,* 2007). Cover crops and mulches are least explored in Asia-Pacific region, compared with Europe and USA, where growing of cover crops is a frequent practice. Many species are available, which can be thoroughly tested and utilized for weed control in the Asian-Pacific region, in future.

Allelopathy

Allelopathy means the chemical interactions among plants where some plants impact the growth and development of other plants through production and execution of allelochemicals. Allelopathy has potential to provide environment-friendly weed control. The allelopathic potential of major crops grown in the Asian-Pacific region may be exploited to manage weeds. For example, rice is known to have allelopathic potential and is grown on a large area in Asian- Pacific countries, such as China, India, Bangladesh, Pakistan, Vietnam, Myanmar, Japan and others (Chauhan *et al.,* 2017; Farooq *et al.*, 2008; Jabran 2017b).

Rice cultivars possessing allelopathic potential may be grown to suppress weeds (Jabran 2017a; Table 2). The allelopathic potential of Super Basmati, a popular rice cultivar in Pakistan, was reported by Farooq *et al.,* (2008). Allelopathic rice and its role in weed control has been reported from Japan, China and some other Asia Pacific countries as well (Berendji *et al.,* 2008; Kato-Noguchi *et al.,* 2010; Kong *et al.,* 2008, 2011).Allelopathic crops other than rice and wheat have also been reported from Asian-Pacific region

(Asaduzzaman *et al.,* 2014; Jabran *et al.,* 2008,2010a). Canola (*Brassica napus* L.), sorghum, maize (*Zea mays* L.) and sunflower (*Helianthus annuus* L.) are important in this regard (Asaduzzaman *et al.,* 2014 ; Jabran *et al.,* 2008, 2010a, b).

In Australia, Asaduzzaman *et al.,* (2014) evaluated several canola cultivars for their allelopathic potential and found that the ones having the highest allelopathic activity against weeds (*Hordeum leporinum*, *Lolium rigidum*, *Sisymbrium orientale*, *Capsella bursa-pastoris*) were Atr-beacon, Av-opal, Rivette and Sardi603. The use of allelopathic rice mulches and water extracts is another option. Allelopathic water extracts of rice could suppress several weeds in canola in Pakistan (Jabran *et al.,* 2010a). Allelopathic potential of wheat and its role in managing weeds has been reported but exploited least compared with sorghum or wheat, particularly for the Asian-Pacific region (Jabran, 2017a,b,c,d).

Table 2: Allelochemicals reported in rice (Adopted from Jabran et al., 2017b)

Allelochemicals	References
Momilactones A and B	Schmelz *et al*., 2014
Cinnamic acid, p-hydroxybenzoic acid, p-coumaric acid, m-coumaric acid	Berendji *et al*., 2008
Ferulic acid, 3,4-hydroxybenzoic acid, coumaric acid, vanillic acid	Bi *et al*., 2007
Coumarin, m-coumaric acid, hydro-cinnamic acid, p-coumaric acid, ferulic acid, caffeic acid	Chon and Kim, 2004
Benzoic acid, p-hydroxybenzoic acid, syringic acid, o-hydroxyphenylacetic acid, p-coumaric acid, o-coumaric acid, m-coumaric acid, ferulic acid, salicylic acid	Chung *et al*., 2001 Chung *et al*., 2002

Allelopathy has a potential to be utilized as a weed control technique in the Asian- Pacific region. However, more research work is required, owing to knowledge gaps and information deficiency regarding the utility of allelopathy for weed control and its environmental benefits. Intensive research work is needed on screening, selection and breeding of crop genotypes with high yield and an allelopathic potential. Genetic engineering tools may also be used to produce crop cultivars possessing superior allelopathic traits.

Biological Control

Biocontrol Agents as potential, Eco-friendly Resources in Weed Management

Biological management of weeds through introduction of the natural enemies like insects, pathogens, etc., that regulate the weed's population, is an effective method of weed control. These biological control agents provide an eco-friendly, self-sustaining and cost-effective alternative to chemical control. Biological control has been applied against more than 135 weed species, using more than 350 control organisms, in about 51 countries since 1865. There are some promising bioagents, which have made success stories for the management of some important weeds in several countries in the Asia Pacific Region. Bioherbicides have been gaining increasing attention and interest among those concerned with developing environmental friendly, effective and compatible approaches for integrated weed management for the noxious weeds, especially to replace chemical herbicides.

Microbial control of weeds: Fungi are particularly superior biocontrol agents because they have a high reproductive ability, a short generation time and are often able to survive as resting structures or as saprophytes during periods when host plants are not available. Several microbial products have been patented and commercialized in well-advanced countries (Boyette, 2000; Charudattan and Dinoor, 2000). DeVine®, developed by Abbott Laboratories, USA, was the first commercial mycoherbicide derived from fungi *Phytophthora palmivora* Butl., a facultative parasite that produces lethal root and collar rot of its host plant stangler vine (*Morrenia odorata* H. and A. Lindl.) and persists in soil as spores for extended period giving a long term control (Templeton, 1987).

As has been reviewed by Boyette (2000), other fungal bioherbicides commercially released include Collego® (based on *Colletotrichum gloeosporioides* f. sp. *aeschynomene*) to control Northern Jointvetch [*Aeschynomene virginica* (L.) Britton, Stearns & Poggenb]; ABG5003 (*Cercospora rodmani*) against water hyacinth [*Eichhornia crassipes* (Mart.) Solms], BioMal® (*Colletotrichum gloeosporioides* f. sp. *malvae*) against Round-leaved Mallow (*Malva pusilla* Sm.), Casst™ (*Alternaria cassiae*) against sicklepod (*Cassia obtusifolia* L.), and Stumpout® (*Cylindrobasidium laeve*) for suppressing regrowth from cut stumps of big leaf maple (*Acer macrophyllum* Pursh).

Host specific microorganisms especially fungi have been known for their mycoherbicide potential. Plant pathogenic fungi and bacteria produce a wide array of metabolites including alkaloids, glycosides, peptides, phenolics, terpenoids with wide range of ecological and industrial utility (Vurro and Gressel, 2007). These metabolites are one of the most effective biologically based alternatives to chemical herbicides with low specificity and biodegradability. Fungal species like *Alternaria*, *Penicillium* and *Fusarium* biosynthesizes large number of bioactive compounds. The path of successful commercialization and large scale production of microbial metabolites has proved long and difficult and yet, research and development of microbial metabolites is to be continued and accelerated.

Plants produce an incredible diversity of low molecular weight organic compounds known as secondary metabolites (Pichersky and Gang, 2000) largely represented by terpenoids, phenylpropanoids/ benzenoids, phenolic acids, alkaloids, coumarins, quinines, cyanogenic compounds, ethylene, flavonoids, fatty acid and amino acid derivatives. These volatile compounds are released from leaves, flowers and fruits into the atmosphere and from roots into the soil. Many of these plant-derived compounds have been utilized for wide range of purposes, namely medicines, poisons for hunting, hallucinogens, etc. (Salim *et al*, 2008).

The primary functions of airborne volatiles are to defend plants against herbivores and pathogens, to attract pollinators, seed dispersers, and other beneficial animals and microorganisms, and to serve as signals in plant–plant interaction. Similarly, the root borne metabolites inhibit growth of nearby plants. Within Weed Science, we refer to these metabolites as allelochemicals or phytotoxins. Many allelochemicals produced by plants that inhibit the growth of other plants have been discovered (Putnam, 1988). The numerous successes attained by these bio-herbicides in the period dominated by chemical control give some measure of benefits that will accrue when research into biological forms of weed management are supported by government on a scale that allows their fullest exploitation.

Biocontrol Agents in Integrated Weed Management

Often a successful biological control programme against enduring weeds requires the release and establishment of multiple agents exerting cumulative impacts (Denoth *et al.,* 2002; Moran, 2005; Syrett *et al.,* 2000) or application with other control methods of weed management. Morrison *et al.,*

(1998) demonstrated that chrysomella beetles *Chrysolina hyperici* can augment biological control of St. John's Wort (*Hypericumper foratum* L.) seedlings by transmitting the fungal pathogen *Colletotrichum gloeosporioides* f. sp. hypericum during foraging and feeding. *Mycoleptodiscus terrestris* is known to facilitate greater efficiency of herbicide treatments due to short-term stresses on aquatic weed, Hydrilla causing increased tissue damage (Netherland and Shearer 1996; Shearer 1998; Shabana *et al.,* 2003).

Similar reports of enhanced fungal infection due to insect feeding have been reported by several other researchers (Alford *et al.,* 2003; Gratwick, 1992; Ray and Hill, 2012) as well. Further, double and triple pathogen combination have also resulted in causing larger lesion diameters on target weed, as compared to any of the pathogens tested singly against a target weed (Ray *et al.,* 2008a). As an example, for the management of the aquatic weed, water hyacinth [*Eichhornia crassipes* (Mart.) Solms], Ray *et al.,* (2008b) recommended the integration of herbicide glyphosate at low concentration with two the biocontrol agents – the weevil *Neochetina bruchi* Hustache and the fungus – *Alternaria alternata* (Fr.) Keissl. However, at higher concentrations, glyphosate could have detrimental effects on the activity of the biocontrol agents. Therefore, it is necessary to judiciously combine chemical and biological control, over both time and space, and this may help reduce the weed management costs by improving the overall management efficiency in an environmentally sound way.

The Future of Biological Control of Weeds

A successful biological control programme eventually reduces, or in some cases eliminates, the need for conventional (often chemical) methods of control for a weed species that is growing prolifically in the absence of its natural biocontrol agent. Many aspects of the activity of the bioherbicides can be tremendously improved specially for the pathogens such as increased virulence, improved toxin production, altered host range, resistance to chemical herbicides, altered survival or persistence in the environment, broader environmental tolerance, increased propagule production in fermentation systems, enhanced tolerance to formulation process, and innovative formulation approaches can be enhanced using genetic and other biotechnological techniques. The advances in genetic engineering have opened new vistas to enhance the biodegradable and reclamation abilities of the naturally occurring microorganisms and associated invasive plants.

Climate Change and Weeds

There are abundant evidences that climate change has caused phenological shifts that eventually can result in change in geographic distribution and abundance of range of species including animals and plants (Bradley *et al.,* 2010; Parmesan and Yohe, 2003; Parmesan 2006; Philippart *et al.*, 2011; Parmesan and Yohe, 2003; Thomas *et al*, 2001; Walther *et al.,* 2002;). It is expected that the environmental changes will bring about a shift in the floral composition of wide range of ecosystems, as changes in CO_2 levels, temperature and rainfall pattern will be reflected on flowering, fruiting and seed dormancy and hence the herbivores and carnivores next in food chain shall be impacted (Amare, 2016). Different species may differ in their response to climate change.

It is predicted that climate change will cause range shift of number of species and may facilitate them to become invasive. When native species are stressed by climate change they may often be replaced by exotic invasive species. Native plants are more vulnerable to climatic changes and hence susceptible to displacement by weeds, because the pool of weeds is very large (Dukes, 2000). Weeds will possibly positively benefit from climate change, as they have a greater genetic diversity and adaptive capacity than crops. There is a greater possibility that weeds will have better chances of adapting and surviving photoperiod, water, nutrients or carbon dioxide changes within the environment (Amare, 2016).

The potential distribution of the noxious weed, *Lantana camara* L. may reduce in some parts of the world including its native range South America, but may increase in the colder parts of North Africa, Europe and parts of Australia which are climatically unsuitable at the moment (Taylor *et al.,* 2012). The wild (red/weedy) rice was seen to be at a more advantage than cultivated rice due to rise in carbon dioxide in terms of higher seed yield and plant biomass (Ziska *et al.,* 2010).

The changes in environmental parameters will not only affect the weeds but also their control (Amare, 2016). Increase in carbon dioxide concentration was reported to reduce the glyphosate efficacy against target weeds (Ziska *et al.,*1999). Several biocontrol agents may be rendered ineffective following long periods of high temperature, as seen in *E. catarinensis*, a biocontrol agent of aquatic weed water hyacinth (Ismail *et al*, 2017). An elevated CO_2 level may lead to a decrease in the nutritional value of plants and hence, reduce the fecundity and survival of the associated biocontrol agents (Amare, 2016). This type of effect may reduce the effective abundance of bio-control agents to control the target weed.

While some generalisation may be made, the effects of climate change on native vegetation across large landscapes and fauna are difficult to predict, due to the uncertainty associated with climate change predictions, as well as the inadequate understanding of the impacts of climate change on all aspects of ecosystems. The differential responses of C_3 and C_4 plants to an elevated CO_2 and temperature, in association with humidity, wind pattern, etc., may impact the ecological interactions between species including competition between weeds and crops (Singh *et al.,* 2016). Climate change may also have direct or indirect effect on various mechanical, chemical and biological control methods by reducing or enhancing their effectiveness on weeds.

Thus, strategies for weed management need to be developed for changing climatic conditions. Many countries in the Asian-Pacific region are geographically vulnerable and highly exposed to the damaging impacts of climate change (Filho, 2015). Proper planning for weed management with the changing environmental condition may be a key factor in saving the biodiversity and supply food for the growing population.

Conclusions

Weed Science is important for sustainable crop production but unfortunately this discipline is mostly neglected and misunderstood in most parts of the world. It is a discipline that is mainly perceived as science of herbicides rather than science of weeds. Alternate and new approaches (non-chemical) to weed management need to be explored and tested across multiple crop production systems.

The resources allocated to Weed research are negligible when compared with those of insects and diseases. More funding to weed research is needed for effective future weed management in Asian-Pacific region. Greater resources would be needed for basic research on the biology and ecology of weeds, especially in the context of changing climate. Very few trained weed scientists are available and enrolment of weed scientist students is declining in agricultural universities in most countries.

Urgent attention needs to be given to popularize Weed research among young students and early professionals to develop trained manpower in the field of Weed Science. It is impossible to achieve complete control of weeds by using any single technique alone. Integrated weed management is a key to the sustainability and development of new weed management systems. We need to integrate more effective and economically feasible methods for the management of weeds in the region. Overall, the future of Weed Science in Asian-Pacific region offers hope but consistent effort is needed in all areas to effectively manage weeds in the region.

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‘Beautiful Blue Devil’ or ‘Cinderella’? Perspectives on opportunities to use water hyacinth (*Eichhornia crassipes* [Mart.] Solms)

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Abstract

Much maligned as “*The Beautiful Blue Devil*”, the floating aquatic plant water hyacinth (*Eichhornia crassipes* [Mart.] Solms)continues to be regarded as the *World’s Worst Aquatic Weed*. Historically, management of this weed has relied on physical removal, herbicides, and biological control. Each of these methods has its benefits and drawbacks. Paradoxically, there is abundant information which indicate that the plant’s strengths can be exploited for human benefits. With a capacity to double its biomass every 6-18 days under tropical and sub-tropical conditions, water hyacinth can produce up to 5000-6000 tonnes of fresh matter/ha/year (*ca*. 600-800 kg dry matter/ha/day) in sewage ponds and other nutrient-enriched waters. The utilization of water hyacinth, reviewed in this paper, is an approach that allows us to derive environmental and economic benefits from the plant’s capacity to grow rapidly and produce large biomass under favourable conditions. The list of practical applications is impressive, although commercial adoption of the applications has thus far been slow.

We suggest robust promotion and adoption of utilization as a workable approach, particularly in communities faced with persistent or recurrent water hyacinth infestations, but with few options to control it other than by manual or low-tech methods of removal. In our view, water hyacinth is the flag-bearer for the promotion of the utilization value of colonizing plants in a variety of human endeavours. Although utilization of water hyacinth is not likely to be an option for all types of infestations or regions, it is possible to judiciously integrate well-researched practical uses into a utilization strategy. By combining utilization with emerging concepts such as ‘learning to live with weeds’, we believe it is possible that this extraordinary plant may not be maligned for long as “*The Beautiful Blue Devil*”, but respected as the “*Cinderella*” among weeds.

Keywords: Aquatic weeds, Utilization, Water hyacinth, Water purification, Value-added products

Introduction

Aquatic plants serve a variety of functions in waterways, some of which, such as oxygenation, are vital to the overall health of the aquatic environment. While there is global consensus that some level of aquatic plant growth is necessary for the health of waters and that excessive aquatic weed growth is unacceptable, it is difficult to decide the level of macrophyte density that is ideal for different water bodies. However, the predominance of one species can directly cause imbalances in the aquatic ecology and environment, or indirectly impede the uses of water. Because of their immense capacity to grow rapidly, proliferate,

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and invade waterways, many aquatic plants can grow excessively in response to nutrient enrichment and other anthropogenic influences, such as impediments to natural flow caused by dams and weirs, sedimentation, and influx of urban storm water and sewage effluents. Excessive amounts of aquatic weeds can adversely affect water resources by blocking irrigation canals and pumps, interfere with hydro-electricity generation, waste water by evapotranspiration, hinder boat traffic, increase opportunities for water-borne diseases, interfere with fishing and aquaculture, and also clogrivers, streams, and canals, thereby impeding drainage and causing flooding (National Academy of Sciences, 1975; Penfound and Earle, 1948; Pirie, 1960; Rogers and Davis, 1972; Sushilkumar, 2011).

Water hyacinth (*Eichhornia crassipes* [Mart] Solms; Family: Pontederiaceae) is one such aquatic plant that can easily dominate waterways, wherever it occurs. It is a free-floating macrophyte, native to the tropical Amazon Basin in South America. Historically, it was introduced into many parts of the world as an ornamental plant due to its beauty, unusual appearance, and lavender blue flowers (Gopal, 1990; Wilson, 2005; CABI, 2015). Soon it naturalized in many sub-tropical and tropical regions of the world, in over 50 countries across five continents and became a significant economic and ecological burden, justifiably leading to Holm *et al*. (1977) naming it as one of the ten 'Worst Weeds' in the world. More recently, it has been identified by the International Union for Conservation of Nature (IUCN) as one of the 100 most cumbersome, global, invasive species (Téllez *et al*., 2008). With the warming of the planet in the coming years as predicted by recent climate change models, a further increase in water hyacinth's distribution to higher latitudes is expected (Rahel and Olden, 2008).

Water hyacinth was introduced in India in 1896 at the Royal Botanical Garden, Kolkata, as an ornamental plant. Since then, it has spread throughout the country, infesting numerous water bodies. It has had such major impacts on the economy and the ecosystems that it was named '*The Terror of Bengal*'. In the Asian-Pacific region, since its introduction perhaps more than a century ago, it has aroused great concern in several countries. As highlighted at the first APWSS '*Interchange*' in 1967, water hyacinth was recorded as a major weed in Hawaii, Philippines, Australia, Indonesia, Thailand, Sri Lanka, Malaysia, Fiji, New Caledonia, and Cook Island (Saki *et al*., 1967). Papers presented at subsequent, but early conferences have highlighted its growth characteristics, impacts (Ueki, 1975; Widyanto, 1975; 1977), biological control (Wright, 1979), chemical control options (Widyanto, *et al.*, 1977), as well as nutrient removal potential (Oki, *et al*., 1981).

The dense growth of water hyacinth obstructs water flow in irrigation channels, increases sedimentation by trapping silt particles, and interferes with navigation and hydroelectricity power generation by forming impenetrable mats of floating vegetation (Vietmeyer, 1975). In India, water flow in some irrigation canals has been reduced by as much as 40-95% by this weed (Walia, 2003; Mathur *et al*., 2005). It also poses a grave threat to native flora and fauna and seriously depletes water bodies of oxygen.

Raynes (1964) suggested that the biological oxygen depletion from the organic load of one hectare of water hyacinth mat is equivalent to that of the sewage generated by 80 people. Water hyacinth also increases evaporative water loss from water bodies, and provides a breeding ground for vectors carrying malaria, bilharziosis, and river blindness. In rice fields, water hyacinth could interfere with seed germination and seedling establishment, resulting in heavy economic losses (Mathur *et al*. 2005). The problems caused by water hyacinth are most severe in developing countries, where human livelihoods are closely linked to freshwater rivers, streams, lakes, and wetlands.

Concern over the economic damage caused by water hyacinth, particularly in navigation and irrigation canals in the USA led to the launching of the *Hyacinth Control Journal*, a scientific publication dedicated initially to water hyacinth but later expanded to cover all aquatic plants and renamed the *Journal of Aquatic Plant Management* (see: Review of the history of Weed Science by Chandrasena and Rao in this Volume).

Management of water hyacinth. Among the options for managing or controlling water hyacinth are prevention of its spread and removal of infestations by hand or mechanical harvesters and disposal of the harvested biomass on land; use of chemical herbicides to kill it; use of biological control agents to reduce its growth rate and debilitate and cause decay or even death; and integrated control using combinations of the three methods. Physical control, using mechanical dredgers, draglines, harvesters with various types of saws and choppers and harvester-conveyer-dumper combinations are commonly used (Gallagher and Haller, 1990, Gutierrez *et al*., 1996). However, these methods are not suitable for all situations, and they provide only short-term solutions, in addition to beingcostly to implement.

Common herbicides used against water hyacinth are: 2, 4-D (2, 4-dichloro-phenoxyacetic acid), diquat (1, 1´-ethylene-2, 2´-bipyridylium dibromide salt) and glyphosate (*N*-[phosphonomethyl] glycine). Although these chemicals quickly kill water hyacinth, extensive herbicide use in water is undesirable, due to their non-target environmental impacts, such as deoxygenation caused by the large-scale collapse and decay of infestations, toxicity to aquatic life, and presence of chemical residues in water. Furthermore, the collapse and sinking of large mats may prevent sunlight from reaching the benthic zone, thereby adversely affecting other natural flora and fauna, and creating eutrophic conditions (Nagendra Prabhu, 2016). As a result, there has been considerable interest in the biological control of water hyacinth, which offers probably the most cost-effective management option (Charudattan, 2001a, and references therein).

The subject of biological control of water hyacinth has been widely reviewed (See Center, 1994, Charudattan, 2001a, 2001b; Ray *et al*., 2008, Shearer, 2008). Several arthropod biocontrol agents, notably two weevils, *Neochetina eichhorniae* and *N. bruchi* (Coleoptera, Curculionidae), and the moths *Niphograpta albiguttalis* and *Xubida infusella* (Lepidoptera, Pyralidae) are the most widely used in many countries (Center, 1994; Winston *et al.*, 2014). These insects have provided excellent control in many locations around the world.

Various fungal pathogens, among them *Alternaria eichhorniae*; *Cercospora rodmanii*; *Myrothecium roridum*; *Uredo eichhorniae*, and *Acremonium zonatum* have also been extensively studied (Charudattan, 2001b; Martínez Jiménez and Gutiérrez López, 2001; Shabana *et al*., 2003). Although use of pathogens as stand-alone bioherbicides to control water hyacinth has not been successful (Shearer, 2008), bacteria and fungi area natural cofactor in the weakening and death of insect-attacked water hyacinth plants (Charudattan, 1986; Ray and Hill, 2012). For a complete list of biological control agents of water hyacinth deployed around the world and their relative success in various countries, see Winston *et al.* (2014).

The water hyacinth dilemma. Called '*The Beautiful Blue Devil*' (Vietmeyer 1975), water hyacinth epitomises a dilemma that aquatic weeds pose: while this species could cause potentially significant losses in the use of water bodies, aquatic habitat, and water itself, it can be exploited for a variety of uses, such as wastewater treatment, animal feed, soil additives, bio-fuel production, pollution remediation, and other domestic and industrial uses (Gopal, 1990; Gunnrasson and Petersen, 2007; Lareo and Bressani, 1982; Little, 1979; Pottail *et al*., 2012; Pirie, 1960; Thomas and Eden, 1990; Vietmeyer, 1975).

The problems posed by water hyacinth can be manifested locally or regionally, and are particularly severe in tropical countries where warm water and long growing season can foster its prolonged growth. The problems can be worsened by enrichment of water by fertilizer runoff and nutrients from human and agricultural wastes, as well as industrial wastes. Yet, as Pirie (1960) suggested in the influential journal *Nature*, *"…Aquatic weeds, such as water hyacinth, constitute a free crop of great potential value – a highly productive crop that requires no tillage, fertilizer, seed or cultivation…."* In line with this proposition, there has been a sustained global interest over the decades in using water hyacinth to benefit humanity. In this paper, we have attempted to review relevant literature to identify those uses of water hyacinth that may be developed and implemented around the world, including in the Asian-Pacific region. Our contribution adds to other recent reviews on this topic (Gunnarsson and Petersen, 2007; Jafari, 2010; Yan *et al.,* 2017; and others).

Growth and Biomass Potential of Water hyacinth

An important characteristic of water hyacinth as a colonizing species is its rapid rate of vegetative reproduction by means of offsets. Owing to the brittleness of the stolons connecting the offsets to the mother plant, they are easily broken, setting free the daughter plants as potential colonizers. Evidence indicates that newly produced offsets will grow at rates equal to the parent plant and will produce its own offsets within about 50 days. Commenting on this, Sculthorpe (1971) wrote: "*In a suitable habitat, during active growth, plants can double their numbers every 2 weeks, the floating mat extending by as much as 0.5 to 0.75 m per month…*"

Earlier, Penfound and Earle (1948) had calculated that at this rate of multiplication, 10 individuals would produce 655,360 plants, equivalent to a solid acre, in one growing season in Louisiana (March to November). Reviewing the global literature, Gopal (1990) suggested that water hyacinth can double in plant numbers in just 6-18 days under tropical and sub-tropical conditions, readily forming cohesive floating mats, which can cover large areas of a water surface in a short period of time. Hence, it is not surprising that massive populations of water hyacinth build up when it is introduced into new areas that are conductive for its growth and proliferation. Estimates of biomass yield vary, as growth conditions determine the plant's response, including nutrient levels and prevailing climatic conditions (Oki *et al.*, 1981). Doubling its biomass every 6-18 days, water hyacinth can produce about 930 to 2900 tonnes of fresh matter/ha/year - about 125 to 400 kg of fresh weigh/ha/day (Lareo and Bressani, 1982; Thomas and Eden, 1990). In some early studies, Knipling *et al*. (1970) recorded stands of 470 tonnes/ha of water hyacinth, and weight gains of 4.8% per day. Given that the biomass is about 90-94% water (Abdalla and Abdel Hafeez, 1969; Boyd, 1969; Book, 1969; Little, 1979), this growth is equivalent to approximately 48 to 145 tonnes dry matter/ha/year. The growth in sewage treatments ponds is much higher, up to 600-800 kg dry weight/ha/day (Wolverton and McDonald, 1976), which is equivalent to 5000-6000 tonnes of fresh biomass/ha/year. This rate of yield far exceeds those of the most productive agricultural crops (Wolverton and McKown, 1976).

Although, the water hyacinth plant is mostly water, it has sufficient amounts of fibrous tissue and a high energy and protein content (Boyd, 1969; Little, 1979 and references therein), Many early papers, reviewed by Little (1979), indicate the composition of the water hyacinth tissue, based on weight, to be: water (90-94%); carbohydrates (3.9%); crude fibre (2.2%); crude protein (0.9%), and crude fats (0.4%). The extractable crude protein is about 35.7% of the dried matter (Boyd 1970). Thus, it is possible to utilize water hyacinth for a variety of useful applications, as reviewed below.

Opportunities for Utilization of Water Hyacinth

With recent global sustainability trends in recycling of resources and waste reduction, there is significant interest in harvesting water hyacinth biomass and utilizing it in beneficial ways as raw materials for a range of products. However, exploiting water hyacinth for useful purposes is not a new concept; this subject has been widely reviewed (Gunnarsson and Petersen, 2007; Jafari, 2010; Little, 1979; National Academy of Sciences, 1975; Wolverton and McDonald, 1976; Yan et al., 2017). Despite promotion by sources such as the National Academy of Sciences, USA as early as the mid-1970s, adoption of the plant's utilization potential has been surprisingly slow. A reason, in our view, is that the objectives of management/control and utilization are not compatible from a practical standpoint. Management/control operations are typically based on a decision to rid the infestation. The operations are time-sensitive, irregularly scheduled, and not amenable to fit into a supply-chain.

On the other hand, utilization with a revenue-generation objective would require a steady supply of raw material to meet a set production schedule and an assured return on investment. An alternative is to consider utilization on a cottage-industry model to generate revenue for communities that are beset with water hyacinth infestations but lack the means for their control. In such situations, an integrated, multi-use strategy may provide economic returns and well-being to the communities. In this regard, the following are uses of water hyacinth that we think would be suitable.

Water purification – The 'Water Hyacinth Method' and the 'Water Hyacinth Scrubber'

Popularised in the USA in mid-1970s with extensive research and applications, supported by the National Aeronautics and Space Administration's (NASA) National Space Technology Laboratories, water hyacinth became world famous as a plant ideal for sewage effluent and wastewater treatment, and was proposed as a plant that could even be used in spaceships to the moon. Water hyacinth was 'farmed' in sewage lagoons and grew in sub-tropical conditions at the rate of 20-40 tonnes/ha/day. Its growth removed nitrogenous (N) waste of over 2000 people and phosphorous (P) waste of over 800 people (National Academy of Sciences, 1975 and references therein). In some early studies, under Indonesian conditions, Soerjani (1977) reported that the potential for annual removal of N and P by water hyacinth from water was 313-777 kg N/ha and 96-238 kg P/ha with a population equivalent of 78-190 and 70-175 persons, respectively. Yet, we find it quite surprising that this technology has not been widely adopted in the Asian-Pacific region.

As reported in the 1970s (Vietmeyer, 1975; Wolverton and McDonald, 1976; Little, 1979), water hyacinth doubled every 6-7 days in Florida's growing season (March-November). When 2.2 million litres of sewage/ha/day was passed through a pond containing water hyacinth, the plants removed 80% of N and 40% of P in two days, leading to the establishment of '*The water hyacinth method*' for sewage effluent treatment. Water hyacinth also removed faecal bacteria, odour-causing compounds and reduced suspended matter, leaving a clear, odourless effluent with much reduced N and P. Additionally, the vegetation fostered the establishment of a healthy diversity of macroinvertebrates and zooplankton (such as Daphnia), which fed on bacteria, and the shading caused by the large, floating biomass reduced nuisance algal growth, as well as wind and wave action, thus helping suspended matter to settle out.Given that water hyacinth is so prevalent and naturalized in the warmer states of USA (Florida, a few other southern states, and parts of California), water purification using water hyacinth Systems are now available in USA through a patented system (HydroMentia, 2005).

Decades of research and operations have led to the design of a *Water Hyacinth Scrubber* (WHS™), which is composed of two equally-sized 4-feet deep treatment cells of approximately 1.25 acres (0.5 ha) that operate in parallel. These units are used to cultivate free-floating water hyacinth, which removes N and P and other pollutants from the water through direct plant uptake via the root system. The plant biomass is then recovered for other uses through periodic harvesting. The water hyacinth biomass also supports a diverse community of bacteria and invertebrates that provide additional pollutant uptake and removal. Frequent harvesting of the biomass with specifically designed harvesting equipment maintains the WHS™ at maximum productivity, creating an optimal system for nutrient removal.

Pollution removal and heavy metal phytoremediation

Phytoremediation, using aquatic plants for removal of various pollutants from water, is a well-established technique to reduce water pollution from industrial wastes. A review of literature indicates that water hyacinth is one of the best plants for use in phytoremediation, because it has the capacity to take up, bio-accumulate, and bio-magnify various heavy metal contaminants present in water. Most researchers consider water hyacinthto be a hyper-accumulator of heavy metals like copper (Cu), cadmium (Cd), nickel (Ni), silver (Ag), chromium (Cr), iron (Fe), zinc (Zn), magnesium (Mg), manganese (Mn), cobalt (Co), strontium (Sr), lead (Pb), mercury (Hg), potassium (K), arsenic (As), organic pollutants like phenols, dyes, diphenamid dyes, and photographic pollutant (Ingole and Bhole, 2003; Moyo *et al.*, 2013; Satyakala and Jamil, 1992; Tiwari *et al.*, 2007).

Studies by Wolverton and McKown (1976) had earlier demonstrated that one hectare of water hyacinth could potentially remove 160 kg of phenol per 72 h from polluted water. The involvement of extensive populations of water hyacinth in the clean-up of both sewage effluent and heavy metal pollution in wastewater in the world-famous East Calcutta RAMSAR Wetlands has been well-documented (Chaudhuri *et al*., 2012, and references therein). Water hyacinth has been successfully used for advanced water treatment in sewage, sugar, palm oil, tannery, and other engineering industries (Trivedi and Thomas, 2005). In Sangli (Maharashtra, India), a water treatment plant has been in operation, which treats domestic sewage in water hyacinth culture (Walia, 2003).

Ghabbour *et al.* (2004) isolated humic acids from leaves, stems, and roots of water hyacinth growing in the Nile Delta in Egypt and suggested that these acids confer the strong metal and organic solute binding capacity to the species. They reported that higher concentrations of the acids in the plant tissues are directly correlated with its metal-binding functions. Studies from Bangladesh (Islam *et al*., 2013; Misbahuddin and Fariduddin, 2002) have confirmed that water hyacinth could be used as an inexpensive means of removing arsenic from contaminated drinking water at the household level. The effectiveness of removal depended on the amount of water hyacinth, amount of arsenic present in the water, duration of exposure, and the presence of sunlight and air.

Pinto *et al*. (1987) recovered 70% percent of silver from a silver solution with 98% purity after wastewater treatment using water hyacinth, and then used the harvested plants for recycling the silver from the dried plant tissues. Ebel *et al.* (2007) identified another important application for water hyacinth, namely, to remove cyanide (CN) from effluents produced in small-scale gold mining in South America - an industry where the use of CN is poorly regulated and waste treatment is almost non-existent or insufficient. Water hyacinth could be used to remove CN, because of its high biomass production and tolerance to cyanide and metals. We agree with Ebel *et al*. (2007) that, despite the species causing major problems in some parts of the world, the risk of using it in closed and controlled treatment ponds in areas where the plant is already present should be acceptable.

Despite a wealth of such impressive evidence, water hyacinth's capacity for pollution removal from wastewater produced by many kinds of industries, including mining, and to remove groundwater contamination, these benefits have only been marginally exploited, to date. Due tithe ability of water hyacinth to grow rapidly and tolerate various levels of contaminants due to its unique metal-binding capacity, in our view, this application has the greatest potential among all others.

Production of biofuel

Global depletion of energy sources due to continued over-utilization of non-renewable resources has led to increased interest in biofuel production. Sen and Chatterjee (1931) in their early pioneering work first discovered the generation of power, alcohol, and fuel gas using water hyacinth. Wolverton and McDonald (1976) also reported on the use of the plant biomass to produce biogas containing 60–80% methane, as a promising substitute for natural gas. Research has shown that 374 litres of biogas can be produced from 1 kg of dried water hyacinth. The fuel value of this gas was 21,000 British Thermal Units (BTU)/m^3 compared with 31,600 BTU/m^3 for pure methane (Note: 1 kilowatt hour of energy is equivalent to 3411 BTU).

A continuous supply of water hyacinth can be grown in domestic sewage lagoons to supply biomass in addition to their pollution removal function. One hectare of water hyacinth, fed with sewage nutrients can yield 0.9–1.8 tonnes of dry plant material/day; this biomass can produce 220–440 m^3 of methane with a fuel value of 7–14 million BTU. In addition, the sludge that remains after fermentation can be converted to fertilizer because it retains most of the N, all the P, and other minerals. We find this crucial technology, with multi-faceted benefits, applicable in many subsistence communities across the globe.

Studies in India by Isarankura-Na-Ayudhya *et al* (2007) showed that water hyacinth can be useful for cost-effective mass production of bio-ethanol. In gobar gas plants (plants that produce biogas from cattle dung), the dung can be substituted by water hyacinth biomass, and methane gas produced through anaerobic digestion can be used as fuel for cooking. The slurry left can be used directly or after sun-drying as organic manure. Due to the air entrapped in the tissues, water hyacinth biomass needs dewatering and some pre-treatment (maceration and chopping) prior to digestion.

The use of water hyacinth to produce biofuel is a practical way by which the felling of indigenous vegetation for fuel wood by poor people can be mitigated. Recent studies in Kenya (Rodrigues *et al*., 2014) have impressively demonstrated the successful use of water hyacinth briquettes as an alternative to the local wood fuel. The studies showed that with the appropriate levels of technology made available, briquettes can be produced manually or by machine and used as household fuel for cooking and water heating. Key points (Rodriguez *et al*., 2014), in favour of water hyacinth are its abundance and relatively significant heat content, which enable the material to be used as an alternative biomass with economic and environmental advantages.

Davies and Davies (2013) also described the physical and combustion properties of briquettes made from dried water hyacinth biomass in Nigeria, using phytoplankton scum as binder. These studies provide strong evidence that the production of water hyacinth briquettes for fuel is feasible and environmentally friendly, as they compete favourably with other agricultural products.

As fodder and animal feed

Water hyacinth, harvested from clean water bodies, such as flowing rivers and lakes, has been regarded as a good animal feed and a good source for silage (partly fermented, high-moisture stored food) for ruminants (Muzira *et al*., 2003). Chopped water hyacinth, mixed with other roughages, is feed for pigs and waterfowl. However, studies by Tag El-Din (1992) has shown that using water hyacinth hay as sole roughage greatly reduced the average daily weight gain in ruminants. From an early study, Hossain (1959) had reported high incidence of diarrhoea in cattle feeding largely on water hyacinth, possibly due to high alkali content of the plant. However, for sheep, about 30% bean straw roughage, substituted with hay made from dried water hyacinth, did not negatively affect the growth of the animals. Bolenz *et al.* (1990) observed that the presence of needle like crystals of calcium oxalate in water hyacinth tissue could damage the digestive track of animals fed only with water hyacinth. Processing chopped tissue aids in the removal of the calcium oxalate and excess moisture, making the weed effective as animal feed. Other studies (Saint Paul *et al*., 1981; Mohapatra and Patra, 2013) have indicated that diets containing water hyacinth is also an effective fish feed in aquaculture.

Mulch and compost

Within 25-30 years after its introduction in India in 1889, the value of water hyacinth as bio-fertilizer was well recognized (Finlow and McLean, 1917). Due to the plant's high moisture content, water hyacinth biomass can be directly used as mulch in row crops. During dry periods, this biomass can help conserve soil moisture. It is used to mulch tea as it can absorb more nutrients, has a high rate of production, and good mineral composition, which make it a profitable compost material (Trivedi and Thomas, 2005). Partially dried plants can be converted to good quality compost within about 3 months for use, and 15-30 tonnes of water hyacinth compost/ha gives better yield then any fertilizer treatment in pearl millet (Parra and Horstenstine, 1976).

Studies by Polprasert *et al*. (1980) concluded that water hyacinth compost is useful as it can preserve most of the N, P and K in the compost, and the time taken for composting is only about 30 days. Nitrogen content in water hyacinth varied from 1.5 to 4.0% and phosphorus from 0.15 to 0.4% (Walia, 2003). Sannigrahi (2009) showed that water hyacinth vermi-composts had N, P, and K contents as high as 1.36%, 0.41%, and 1.44%, respectively. Studies by Umsakul *et al*. (2010) showed that agro-industrial wastes could be mixed with water hyacinth during composting to improve the product. Water hyacinth during composting process, if treated with soil-borne microorganisms, especially ligno-cellulolytic fungi like *Trichoderma* sp. are more nutrient rich (Packia Lekshmi and Viveka, 2011).

In recent years, edible mushroom cultivation has increased many-fold as a nutritional food source. Dried water hyacinth has been shown to be an ideal and inexpensive substrate for farming mushrooms (Bandopadhyay, 2013; Murugesan *et al*., 1995). One tonne of dried water hyacinth substrate generated about 1.1 tonne of mushroom, thus generating more mushroom than traditional substrates like sawdust. The spent substrate after harvesting mushrooms is rich in protein from the fungal mycelium and is excellent for raising earthworms, which convert it into humus that can be fed to chickens, ducks, pigs, and even cattle. The same substrate can be reused to produce a variety of mushrooms over 2-3 generations. Not only are these eco-friendly technologies, they are also of economic benefit to mushroom farming on small-to-medium scale enterprises, compared to the costlier wheat straw and other traditional substrates.

Chemical products

Phytochemical studies on water hyacinth have led to the isolation and identification of an impressive array of chemical compounds. These include carbohydrates, proteins, amino acids, sterols, flavonoids, and phenalenones (Virabalin *et al*., 1993, Pottail *et al.,* 2012, Cardoso*et al*., 2014). Early studies showed that carbohydrates, such as D-xylose, D-glucose, and traces of L-arabinose can be extracted from water hyacinth leaves, eichhornin, 3-diglucoside of delphinidin, from flowers (Shibata *et al*., 1965), and gibberellin like substances from roots. The roots also yield some homeopathic medicines (Trivedi and Thomas, 2005), and it has been claimed that protein and amino acid concentrates extracted from leaves contain vitamin A. Isolation of stigmasterol, used in some synthetic steroidal drugs, diosgenin used in the synthesis of progesterone, and cortisone has also been reported. Panchanadikar *et al*. (2005) have patented a convenient process of extraction and purification of a-carotene from water hyacinth. The plant is also used for making microcrystalline cellulose.

Water hyacinth is also a source to produce shikimic acid, which is an important intermediate in the biosynthesis of aromatic compounds in plants and microorganisms. Studies by Cardoso*et al*. (2014) confirmed that aerial parts of water hyacinth contain higher shikimic acid concentrations, which can be extracted using methanol as a solvent. Shikimic acid is the main compound to produce antiviral agents against influenza virus types A and B, avian influenza virus H5N1, and human influenza virus H1N1. The activity of water hyacinth extracts as antibacterial, antifungal, and anti-algal (green microalgae and cyanobacteria) antibiotics has been attributed to the presence of various alkaloids and flavonoids in the plant (Joshi and Kaur, 2013; Shanab, 2010; Thamaraiselvi *et al*., 2012). The production of useful chemicals from water hyacinth would require a level of investment in equipment and personnel trained in extraction, purification, standardization, and quality assurance. Nonetheless, a cottage-industry model could be set up if the projected returns from the produced chemicals are sufficiently large.

Other useful products, including paper

Water hyacinth fibre has been used in many countries for making paper (National Academy of Sciences, 1975, Little, 1979). However, water hyacinth fibre alone does not make good paper due to its low quality. Paper made from water hyacinth fibre alone is brittle, wrinkle readily, darken upon drying, and tear easily. Nonetheless, many useful products, including folders and boxes can be made by mixing and blending water hyacinth fibre with recycled waste paper or jute fibre, treating the mixture with bleaching powder, calcium carbonate, and sodium carbonate, and heating.

An enterprise based on water hyacinth, Hyacinth Crafts, "*turns gloom to bloom and doom to boom* "according to Olal *et al*. (2001). Many African and Asian countries have extended the blending technologies to make use of the water hyacinth fibre to make carpets, fibre board, ropes, yarn, baskets, and decorative water hyacinth furniture (Olal, 2003). Such small-to-medium scale cottage industries or projects have been successful in several countries like Bangladesh, India, Sri Lanka, Indonesia, Vietnam, Malaysia, Kenya, Uganda, and Philippines as well as in some semi-industrialized areas of China.

Discussion

Several authors (Gopal and Sharma, 1979; Gopal 1987) have cautioned that although the economic and possible environmental gains from utilization of aquatic weeds can be impressive due to their high productivity, their utilization may lead to an expansion in their infestations for want of a continuous supply of raw materials. This might lead to their introduction into new water bodies.

On the other hand, Gunnarsson and Petersen (2007) have stated, "…*water hyacinths can be rich in N, up to 3.2% of dry matter and have a C/N ratio around 15. It can be used as a substrate for compost or biogas production. The sludge from the biogas process contains almost all of the nutrients of the substrate and can be used as a fertiliser. The use of water hyacinth compost on different crops has resulted in improved yields. The high protein content makes water hyacinth possible to use as fodder for cows, goats, sheep, and chickens. Water hyacinth, due to its abundant growth and high concentrations of nutrients, has a great potential as fertiliser for the nutrient deficient soils of Africa and as feed for livestock*."

Water hyacinth, despite being a major aquatic weed in regions where it is non-native, can be a valuable resource with many unique applications. Our review adds to attempts by other researchers to promote the wider utilization of water hyacinth in regions of the world where it is now naturalised. The justification for considering water hyacinth as a plant to be widely utilized lies in its capacity to produce an enormous biomass that can be converted into a resource for industrial and other household products, including animal-feed supplements, soil conditioners, composts, paper, biogas, handicrafts, and others. These have been well-proven by the impressive corpus of global literature – from USA, India, and other countries.

In our view, the use of water hyacinth for water purification and removal of heavy metal contaminants probably has the most beneficial, immediate application in developing countries in Africa and Asia. In most other applications, water hyacinth biomass does not require much processing; simple sun-drying and pressing for de-watering makes the biomass usable in various small-scale industries. Most uses do not require large capital investments and can be implemented, particularly in rural communities in developing countries, with a little assistance from governments or non-governmental organizations.

In an emerging world looking for sustainable future, the management strategy of water hyacinth should be centred on a broad, multi-faceted approach that incorporates biological control integrated with utilization of excessive biomass in cottage industries for beneficial end-uses. In rural areas, water hyacinth could be used in an integrated manner for decentralized wastewater treatment systems coupled to biogas and compost production. Demonstrating the integrated uses, Jianbo *et al.* (2008) described the utilization of water hyacinth to purify organic wastes from a constructed wasteland in an intensive duck farm in China, and provide good quality nutrient-enriched animal feed. Similarly, Singhal and Rai (2003) in India showed that a slurry of water hyacinth that was used for phytoremediation of pulp and paper mill effluent produced significantly more biogas than that produced by the plant grown in deionized water. These, and other studies provide evidence that a renewed effort to promote a holistic approach to water hyacinth management, which includes utilization, is overdue across many in countries around the world.

We conclude that utilization of water hyacinth is a viable approach. Utilization provides an environmental and economic benefit from the plant's extraordinary capacity to grow rapidly and produce large amounts of biomass under favourable conditions. We suggest robust adoption and promotion of utilization options as a workable approach, particularly in communities where water hyacinth infestations are persistent and control options are few. Many communities in the South-Asian region fall in this category.

The global spread of water hyacinth has reached such a proportion that efforts to eradicate it from countries appear futile. However, we believe that by judiciously integrating well-researched uses with practical applications with emerging concepts, such as 'living with weeds' (Chandrasena, 2014), this extraordinary plant may not be maligned for long as "*The Beautiful Blue Devil*" or one of the "*World's Worst Aquatic Weeds*", but respected as the "*Cinderella*" among weeds.

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Section II :
Memories and Reflections

Reminiscences of Initiating a new English Weed Science Journal, *Weed Biology* and *Management*

Kazuyuki Itoh[46]

It is with great pleasure that I send this congratulatory message to the Asian-Pacific Weed Science Society (APWSS) as it celebrates 50 years of existence. I am very pleased that I was part of the APWSS journey and am very happy for the continual publication of the International Journal of *Weed Biology and Management* (WBM), which is affiliated to the APWSS. Here, in this brief contribution, I would like to remember the starting point of the journal.

In the Year 2000, I was the Secretary General of the Weed Science Society of Japan (WSSJ), under Dr. Jiro Harada, the President. At that time, opinion was expressed that we should establish a new scientific journal for our Society, and that this should be entitled *"Weed Biology and Management*". I was also Editor-in-Chief during a 4 year period (2002 to 2006) producing Volume 2, No.3 to Volume 6, No.2 of WBM. Our friend and colleague, Dr. Harada passed away in November2014, and my memories of him are vivid, as I recall the background information of the period preceding the initiation of the WBM Journal.

Initiation of the WBM Journal

Dr. Jiro Harada (at that time, Vice President of the National Institute of Agro-environmental Sciences (NIAES, Tsukuba, Japan) was voted the President of WSSJ in March 2000. He chose me as for the Secretary General of the Society and expressed the view that:"*We will make a new English Weed Science Journal, as soon as possible*" at our meeting on 19th April, 2000 at the Ushiku Citizen Center. This was the 39th annual meeting of the WSSJ (Harada, 1999; Harada, 2000). Although I was very busy those days, I was entrusted with the responsibility of having to decide on the journal title, the focus, style of all pages, instructions for authors and selection of editors etc.

I had previously attended many international conferences or congresses related Weed Science, prior to taking this responsibility. Some of the Conferences I had attended included the following; 8th APWSSConference, Bangalore, India (1981), 10th APWSS Chiang Mai, Thailand (1985), 11th ICPP Manila, Philippines (1987), 4th International Symposium of Plant Biosystematics (IOPB) Kyoto, Japan (1989), 3rd Tropical Weed Science Conference Kuala Lumpur, Malaysia (1990), 13th APWSS Jakarta, Indonesia (1991), 1st International Weed Control Congress (IWCC) Melbourne, Australia (1992), 15th APWSS Conference, Tsukuba, Japan (1995), 16th APWSS Conference, Kuala Lumpur, Malaysia (1997), Brighton Crop Protection Conference, the United Kingdom (1997)and the 17th APWSS Conference, Bangkok, Thailand (1999). During that time, my research interests were largely on the emergence ecology of paddy weeds, especially *Sagittaria trifolia* (Itoh, 1997) and herbicide-resistant Asteraceae

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(Compositae) weeds against paraquat (Itoh and Miyahara, 1994) and paddy weeds developing resistance against sulfonylureas (Itoh *et al.*, 1999; Valverde and Itoh, 2001). Through this research, I developed linkages with a large number of weed scientists and friends from all over the world. Before the WBM was initiated, some of the Weed Scientist I met, who I recall fondly, are those I made friends with at the 3rd IWSC in Iguassu, Brazil 6th -11th June, 2000.

They include: the President of Korean Society of Weed Science (KSWS) - Dr. Kil-Ung Kim, and others - Dr. Jae-Chul Chun, Dr. Yong-Woong Kwon; FAO agronomist - Dr. Ricardo E. Labrada Romero, New Zealand - Dr. Anis Rahman; Australia - Dr. Aik Hock Cheam, Dr. Stephen Powles; from Malaysia - Dr. Anwar Ismail; APWSS Secretary - Dr. Chao Xian Zhang, President of APWSS - Dr. Ze-Pu Zhang; IRRI - Dr. Jim Hill; Poland - Dr. S. W. Gawronski; USA Dr. Albert Fischer; and other Japanese colleagues - Drs. Hitoshi Saka, Sizuko Ishikawa, Kenshi Sakai, Michiaki Kamoi, and Kangetsu Hirase.

Most members that I consulted said that it was difficult to obtain financial support for a Journal, from their countries, but they could provide any editorial support or write reviews and papers. Some people, including Drs. Peter Michael (Australia), Keith Moody (IRRI), and A. Rajan (Malaysia), strongly supported the view of another Journal. They requested me to make the plan, written by English, and send by e-mail, as soon as possible. In the early discussions, it was also pointed out that it would be not good for the new Journal to be named with a regional focus (for example: "Asia" or "Pacific"), and that to publish a new journal, we would need to select an international publishing company, such as Blackwell Science Asia or Elsevier Science.

Finally, our Society decided on the journal title, style, scope, and instructions for authors at an extraordinary Council meeting of the WSSJ on 28th September, 2000. The members present were: Drs. J. Harada, H. Hirota, M. Saegusa, H. Watanabe, T. Yoshioka, K. Kobayashi, H. Matsumoto, H. Morita, N. Takeshita, T.Yamawaki, Y. Yogo, N. Hirota, Y. Kawamura, H. Mizutani, H. Saka, M. Ito, K. Komai, T. Tominaga, H. Yamaguchi, Y. Yamasue, T. Enomoto, J. Itani, Y. Oki, T. Matsumoto, K. Noritake, K. Nakatani and myself.

We decided to give the Journal the name – *Weed Biology and Management* (WBM) and make it an international journal, published four times per year. The Journal was launched accepting contributions in the form of original research, review articles, technical reports and short communications in all aspects of Weed Science. Contributions from weed scientists in the Asian–Pacific region were particularly welcomed, in order to support the APWSS and our region. Contributions could be related to weed taxonomy, ecology and physiology, weed management and control methodologies, herbicide behaviour in plants, soils and environment, utilization of weeds and other aspects of weed science. Editorial standard was set high, and all contributions needed to be of sufficient quality for publishing, so that they could extend our knowledge in Weed Science.

WBM is now sponsored by and is the official English journal of the Japanese Weed Science Society - WSSJ, and is published with cooperation and encouragement of many of the national Weed Science Societies affiliated with the APWSS, including the Council of Australian Weed Science Societies (CAWS), Weed Science Society of China, Korean Society of Weed Science (KSWS), New Zealand Plant Protection Society, Weed Science Society of Taiwan, Weed Science Society of Philippines, Thailand Society of Weed Science and other relevant organizations. We were also advised that the publication should not be carried out in a hurry, however, at an extraordinary Council Meeting, it was decided that WBM (completely in English) should be published from Blackwell Science Asia in March, 2001, as a separate Journal form "*Weed Science and Technology*" (which is completely in Japanese).

The first editorial members of the WBM in 2001 were as follows: Editor-in-Chief: Dr. Katsuichiro Kobayashi, Professor of University of Tsukuba at that time; other Japanese editorial board members - Drs. John L.Breen (Dow AgroScience), Yoshiharu Fujii (NIAES), Kangetu Hirase (Mitsui Chemicals), Kazuyuki Itoh (NIAES), Osamu Kodama (Ibaraki University), Hiroshi Matsumoto (University of Tsukuba), Mamoru Nashiki (NGRI), Masaru Ogasawara (Utsunomiya University), Hiroyoshi Omokawa (Utsunomiya University), Hitoshi Saka (The University of Tokyo), Kenshi Sakai (Tokyo University of Agriculture and Technology), Ie-Sung Shim (University of Tsukuba), Koichi Suzuki (Nissan Chemicals), Yasutomo Takeuchi (Utsunomiya University), Tohru Tominaga (Kyoto Prefecture Unversity), Masako Ueji (NIAES), Kenji Usui (University of Tsukuba), Ko Wakabayashi (Tamagawa University), Guang-Xi Wang (Kyoto University), Hirofumi Yamaguchi (Osaka Prefecture University), Yuji Yamasue (Kyoto University), Yasuhiro Yogo (NARC), and Toshihito Yoshioka (Tohoku University).

The overseas members of the Editorial Committee were: Drs. Aurora M. Baltazar (University of Philippines, Philippines), Aik Hock Cheam (Australia), Duong Van Chin (CLRRI, Vietnam), Chang-Hung Chou (Sun Yatsen University, Taiwan), Jae-Chul Chun (Chonbuk University, Korea), Albert J. Fischer (University of California-Davis, USA), Ja-Ock Guh (Chonnam University, Korea), James E. Hill (IRRI, Philippines), Ahmed Anwar Ismail (MARDI, Malaysia), Kil-Ung Kim (Kyungpook University, Korea), Soon-Chul Kim (RDA, Korea), Yong Woong Kwon (Seoul National University, Korea), Ricardo E. Labrada Romero (FAO, Italy), Hanwen Ni (China Agriculture University, China), Roy Nishimoto (University of Hawaii, USA), Jong-Yeong Pyon (Chungnam University, Korea), Anis Rahman (AgResearch, New Zealand), Rungsit Suwanketikom (Kasetsart University, Thailand) and Ze-Pu Zhang (CAAS, China).

Membership fees for Asian-Pacific Members, outside Japan

In supporting weed scientists of our region, we established a reduced rate for publications for developing countries, similar tithe IRRI Book Shop and IRRI Publications. Also, we established a grant-in-aid (named, "Kaken-hi") for publishing for scientists and students from developing countries from the Japanese Government. It is important to the number of members of the Journal to get the grant-in-aid.

In terms of membership fees for members of overseas, developing countries, we made a discount by increasing the number of members and packaging any shipment of "WBM" to the affiliated local Weed Science Society in each country. This was done with the co-operation of each Society and its primary contact and representative. This system has been already in place in Korea, Taiwan, Thailand and Vietnam. The other membership fee system for developing country Scientists, in the Asian-Pacific was a highly discounted fee of 1500 JPY from 2001. In contrast, the membership fee of Japanese individual members is 8000 JPY, and been so, since 2002. The front and rear cover design that was done in 2001 has also not been changed from the first issue.

Dr. Harada wrote the first page of the journal as follows:

"*…The WSSJ releases the first issue of the new international journal WBM at the beginning of the 21st century in cooperation with the APWSS, many societies in the national level and many individual weed scientists in the Asia-Pacific region. Thus, this journal is for all the scientists in the Asia-Pacific region, although it is published as an official journal of WSSJ…..On behalf of the WSSJ, I would like to express my heartfelt gratitude to all the people concerned with publishing the journal. To conclude, I eagerly hope for your contribution and continuous support for the progress and betterment of the journal…*" (Harada, 2001).

Functioning as Editor-in-Chief (2002-2006), I tried to do my best in those early years. Because the journal had just started, one problem was how to get good quality papers. Submitted papers were not enough at that time, and also we needed review papers on various subjects, including rice cultivation or paddy weeds.

The Impact factor (IF) figure for the journal was not available in the early days. In 2008, the IF was 0.69, which rose up to 0.717 in 2012; it was 0.5 in 2015/16.Editorial members for WBM came from several overseas countries. We made a new editing system with computer-based, electronic editing, around 2007. The system continues to date. The On-line version of WBM commenced in 2006.

Figure1. Japanese editorial members of "Weed Biology and Management" in the time of 41st annual meeting of WSSJ (Source: Tokyo University of Agriculture, Time: April 12th 2002)

Front: left to right: Ms. Kunimi *Tanaka* (Blackwell Publishing Asia), Dr. Kazuyuki *Itoh* (NARCT, Editor-in-Chief), Dr. Katsuichiro *Kobayashi* (University of Tsukuba, Editor-in-Chief), Ms. Yukari *Arao* (Blackwell Publishing Asia), Center: left to right - Dr. Yoshiharu *Fujii* (NIAES), Dr. Yasuhiro *Yogo* (NARO), Dr. Hirofumi *Yamaguchi* (Osaka Prefecture University), Dr. Tohru *Tominaga* (Kyoto Prefecture University), Dr. Toshihito *Yoshioka* (Tohoku University), Dr. Yuji *Yamasue* (Kyoto University), Behind: left to right - Dr. Masaru *Ogasawara* (Utsunomiya University), Dr. Ko *Wakabayashi* (Tamagawa University), Dr. Hiroshi *Matsumoto* (New Secretary General of WSSJ, University of Tsukuba), Dr. Yasutomo *Takeuchi* (Vice President of WSSJ, Utsunomiya University), Dr. Ie-Seung *Shim* (University of Tsukuba), Dr. Mamoru *Nashiki* (NARCT) at the time.

When I examined a recent WBM issue (December, 2016), I can see recent papers in the journal from Cambodia, India, Iran, Thailand, USA, Vietnam and three papers from Japan in the Vol. 16, No. 3/4, published in December 2016. I am pleased that WBM now looks like an international journal. Guest editors and so many reviewers from all over the world have been helping the editorial board. Although, the Science Citation impact factor value of the journal is still a relatively small figure, with time, I think it will gradually become a leading performing Asian-Pacific Weed Science Journal.

Reflecting on the future of Weed Science

Reflecting on the future Weed Science, I am aware that other contributors to this Volume have given broad overviews, discussing the possible future directions of our subject. Therefore, I will limit my comments to two areas of Weed research, which have been of closest interest to me.

How to control herbicide resistant weeds and invading plants?

One of the major purposes of Weed Science and technology is to increase our understanding of weeds, so that they can be better controlled. This can be done through research the biodiversity of weeds, using various approaches of relevant fields, such as ecology, biology, physiology, biochemistry and chemical research. The concept of the biodiversity implies sustainable ecosystems, both agricultural and non-agricultural, plant communities, species interactions, including those of weeds.

With weeds becoming resistant to herbicides, and the adaptability of weeds to various environmental changes and impacts, active utilization of weeds is indicated as a possible important subject. I suggest that by reducing the need for herbicides, ecologically-based weed management strategies can help farmers reduce their input costs, reduce threats to the environment and human health, and minimize the selection for herbicide resistant weeds. I wish to promote utilization of weeds, in this context.

There are now a large number of species invading countries all over the world. Their spread and invasion is assisted by global warming and trade expansion. Invasive plants, like the water lettuce – *Pistia stratiotes* (Tamada *et al.* 2015), and Lantana-*Lantana camara* are already widely distributed in temperate countries. It is our responsibility to understand these weeds and control their invasions.

Under integrated weed management (IWM) approaches for sustainable agricultural production, incorporation of other technologies for weed management are also recommended to farmers. These include cultural, mechanical and biological weed control methods. Progress in IWM is still slow in many cropping systems. Also, we need to promote integrated biodiversity management (IBM) as a means of conservation of the rural landscapes (Itoh, 2004).

How to control root parasitic weeds in Sub-Saharan Africa?

Heavy infestations of *Striga* spp., a root parasitic weed, affect crops, such as maize, sorghum, rice, millets and cowpea yields, particularly in the sub-Saharan Africa (SSA). The reason for heavy infestations is the decrease in the traditional mixed plantations towards monocultures and the increased use of contaminated agricultural machines. Inadequate fertilizer for the cultivation of the crops, where the land is of low soil fertility, does not give any advantage to the crops, and this increases the growth of root parasitic weeds. The most significant in Sub-Saharan Africa are: *Striga hermonthica, S. asiatica, S. Gesnerioides* and *Alectra vogellii*.

Mixed cultivation with some aggressive, legumes forage, cover crops, such as *Desmodium uccinatum* (cv. Silverleaf), *Pueraria phaseoloides* and *Calopogonium mucunoides* are important to achieve better control of *Striga* spp. However, the seeds of these species are costly in the Sub-Saharan Africa, and the establishment of cover crops has no direct effect on the farm income. Therefore, we need integrate the cover-cropping technology or knowledge into systems that generate income (Atera *et al.*, 2012), along with mixed-cropping. Multiple cropping, integrating maize and cassava, or legumes, such as soybean, pigeon pea, cowpea, ground nut, common bean, and the use of cover crops for soil conservation are likely to be successful in future management of parasitic weeds (Atera *et al,*. 2014).

Acknowledgement

I thank the Editors, Drs. Nimal Chandrasena and A. N. Rao, for valuable suggestions and improving this manuscript. I also grateful to them for providing this opportunity to share my thoughts, especially reflecting on the establishment of our Journal – *Weed Biology & Management*.

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Reminiscences of Asian-Pacific Weed Science Society and some perspectives

Kil Ung Kim[47]

I thank the Editors of this Volume – Drs. Nimal Chandrasena and A. N. Rao for inviting me to reflect on the Asian-Pacific Weed Science Society (APWSS) and its achievements and importance in the region. I am honoured to send this congratulatory message to the APWSS in its 50th Anniversary celebrations; and also offer the following reminiscences and perspectives for the Celebratory Volume.

Introduction

Today we are experiencing a rapid change in the development of Science and its applications across almost all human endeavours. Scientific developments and progress during the past 20 years can be compared with those of the past one hundred years; or possibly, even with the past five thousand years period. From now on, it is expected that another great scientific revolution is occurring in the coming ten year period. Creative thinking and innovation are needed in all research areas that affect mankind. In this regard, how to utilize innovative technology in agriculture is fast becoming an important issue. For instance, drone and robot technologies can be used in seeding, spraying chemicals and harvesting, etc. in agriculture, and smart farming is demanded by farmers. How could we adjust to rapidly changing environment of scientific technology?

During the three decades (1970-2000), in our region, we have been benefited from the Asian-Pacific Weed Science Society (APWSS) in terms of developing various options for weed control in crop production and management of landscapes and waterways. These aspects have often been highlighted and discussed at successive APWSS Conferences and at other international meetings. Many papers and books have been published disseminating this knowledge and sharing information with other weed scientists of our region, and beyond. Detailed information on APWSS Conferences is available in the booklet 'Commemorating 40 years of the Asian-Pacific Weed Science Society (1967-2007)' compiled and written by Aurora M. Baltazar.

In addition to the above, in 2017, as APWSS celebrates 50 years of its existence, I wish to highlight some other activities, seminars and conferences held in this region, supported by the Food & Agriculture Organization (FAO), International Rice Research Institute (IRRI), Food & Fertilizer Technology Centre and the Steering Committee for Weed Management for the Asia & the Pacific Region, which was also established with support from the FAO. In Korea, the achievement of food self-sufficiency in 1977 was achieved through rice varietal improvement, and accelerated adoption of improved weed control methods.

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Organization of Asian-Pacific Weed Science Society

Readers know that the APWSS was found by a group of leading weed scientists in the Asian-Pacific region. The first meeting of APWSS was held in Hawaii, USA in 1967. Since then, the Society's Conferences have been held biennially, in different countries. In the 1960s, when APWSS began, most of the countries in this region were very much under-developed, with a few exceptions. This meant that most agricultural practices, including weed control were implemented by manual means, with some farm implements and very little mechanization. Herbicides were not commonly used in most South-Asian and South-East Asian countries, until later. However, in the 1970s herbicides became a major component for weed control in all crops in the region.

Economic developments of each of the countries of the region might be correlated with the choice of method(s) to control weeds in the field, and thereby, increase food production. It is evident that farmers select methods that provide the desired, high degree of weed control at the lowest cost, and therefore, the input prices are an important factor of what method they would chose (De Datta *et al*., 1982). In my opinion, the APWSS biennial Conferences were an important forum for the exchange of Weed Science information, which led to adoption of practices, increased food production and poverty alleviation in the region. As Moody (1985) suggested, based on the likely impact in a highly populated region, the APWSS biennial Conference ranked among the most important Weed Science Conferences in the world.

After the APWSS was established in 1967, the Weed Science Society of the Philippines was founded in 1968; and one year later, in 1969, hosted the 2nd APWSS Conference. Many countries had small groups of weed scientists, discussing weed issues, but few Societies existed in the 1970s, until the 1980s. The Weed Science Society of Korea was established in 1981; and Korea hosted the 12th APWSS Conference at Seoul in 1989. How could we explain the 13 year gap in organization of a national society between the two countries? It may be due to more numbers of trained weed scientists in the Philippines and a better economy in the 1960s compared with South Korea. Exposure to global trends through geo-politics (i.e. Japan and USA) may have also been an important factor.

Weed Science Societies have been formed in developing and developed countries to stimulate cooperation among the many non-specialists and the few specialists working to control weeds (Burrill, 1982). Among the many possible activities, the Societies of each country have the responsibility of organization local, national or regional conferences, to stimulate discussion on the progress being made in weed control around other parts of the world. This requires vision, on a global level, and commitment.

In my opinion, the organization and management of a professional society is something that requires little prior experience, but it needs a few interested and highly committed people. A society, such as the APWSS, is an organized group of people, joined together by a common interest, in this instance, Weed Science, and ultimately, the effective management of weeds for the benefit of farmers, the society at large and the environment.

Rice as Major World Crop

Rice, a major world crop, was produced in about 82 countries during 1977-1979. The average annual world rice production during 3-year period was about 372 million tons grown on 143 million ha (USDA, 1980). Rice is the main food in the densely populated countries of the Asian-Pacific region, including China, India, Indonesia, the Philippines, Japan, and Korea.

The International Rice Research Institute (IRRI) was established in 1962, sponsored and financed by the Ford and Rockefeller Foundations of USA, with the help and approval of the Government of Philippines. IRRI has played very important role in development and dissemination of agricultural technologies to rice producing countries in world. IRRI also offered many different types of training programs including degree program.

Those who were undertaking Masters or Doctoral courses enrolled at the University of Philippines, Los Banos (UPLB) and most students conducted their research at IRRI. Many Asian countries has been suffered from food shortages, particularly due to low yield potential of local rice varieties. Fortunately in late 1960s, dramatic increases of rice yields were obtained through development of new high-yielding, dwarf rice variety, IR 8 at IRRI, which provided a good source for varietal improvement in all rice growing countries.

With regard to rice production, Korea had suffered from food shortages for a long time, until 1976, due to the low yield potential of local rice varieties. The new high yielding variety, Tongil cultivar (IR 667) was bred from three way crossing: IR 8 (♀, indica type) x {Yukara (japonica type) x TN1 (indica type)}. This new variety yielded 30% higher than recommended local japonica type varieties. Tongil cultivars brought rice self-sufficiency in Korea in 1977. Since then, chemical weed control received a great deal of attention.

The rapid industrialization in 1970s began to attract labourers from the country side to work in industry. Thus, hand weeding was rapidly displaced by chemical or integrated control method during late 1970s and 1980s. However, in Japan, as of 1974, over 100% of the total rice acreage was treated with herbicides. When the acreage was taken into account, herbicides were used more than twice a year (Noda, 1975).

First Conference of Weed Control in Rice

In addition to APWSS biennial meeting, there were a number of symposiums or seminars organized by international or national organizations. These were very helpful to disseminate new weed control technology to members of APWSS. One such Conference was held in the IRRI jointly sponsored by the International Weed Science Society from 31 Auto 4 Sep 1981. There were about 70 invited scientists, who were directly involved in weed research, or working at an international agency, such as FAO and CGIAR (Consultative Group on International Agricultural Research) and some participants from Europe.

Many participants were members of APWSS and there were also a large number of participants from USA and Philippines, followed by Japan and a few from developing countries. This meant that there was a great difference in understanding of Weed Science and adopting weed control technology in each country. Through this Conference, as young weed scientists, we were able to learn and share advancement in weed control technologies presented by weed scientists from the more developed countries.

In the 1970s, labour was plentiful and hand weeding was the most common control method in most of Asian-Pacific rice growing countries. I believe that this 1981 Conference at IRRI stimulated each Asian country to pay more attention to weed management in rice. The discussions covered a wide spectrum of weed research: statement of the problem of weeds, factors affecting weed populations; and methods of control; current weed control technologies; weeds, diseases and insect interactions; special problems, such as weed flora shifts; perennial weeds and their control, wild rice and red rice; issues of pesticides and the environment, etc.

Yield and quality losses in rice were estimated at 15% in the US (Smith *et al.*, 1977) and 10% for the world (De Datta, 1980). Smith (1982) summarized factors affecting yield loss in rice-weed competition as follows: competitive efficiency of weed, species or groups of weed, density, duration of weed crop competition, planting method, crop cultivar, fertility level, water management, row spacing of the rice crop, allelopathy, and interactions among some of the preceding factors. These factors are globally applicable as guidelines for investigating the effects of crop-weed competition in any cropping situation.

Training as a Weed Scientist

In early 1970s, as a student, I undertook my own Ph.D. studies under a Rockefeller Foundation Scholarship, at University of Philippines, Los Banos (UPLB) during 1970-1973. This was followed by a post-doctoral fellowship at IRRI during 1973-1974. On reflection, this is a good opportunity for me to express my sincere thanks to Drs. Marcos R. Vega (First President of APWSS) and Beatrice L. Mercado, who were my advisers for the Ph.D. course, and Dr. Surajit Kumar De Datta was my supervisor for the Post-doctoral fellowship at IRRI. Both of Drs. Vega (those days, Deputy Director General at IRRI) and Beatrice Mercado (Professor at UPLB) have now passed away (in 2001 and 1988, respectively). Dr. De Datta left IRRI to take up a position at Virginia, USA in the mid-1990s.

I was appointed as a senior researcher in Rural Development Administration, Korea in 1974 after the post-doctoral research at IRRI. Then, I was asked to multiply newly-bred rice varieties, crossed with IR8. Thus, I was dispatched twice to IRRI during winter time in Korea (in November 1974-April 1975 and November 1975-April 1976) and multiplied 105 tons of Yushin seed on 15 ha of farmer's fields near IRRI during winter 1974-1975 and 70 tons of Milyang 21 and 23 seed on 10.5 ha of the same farmer's fields near IRRI during winter 1975-1976. The seed of both new varieties were flown back to Korea in time to plant during summer 1975 and 1976. The seed of three new varieties were planted throughout Korea in summer of 1977.

In the autumn of 1977, Korea achieved rice self-sufficiency for the first time in its history. This was called 'Korean Green Revolution'. I am very proud of being a major participant in the 'Korean Green Revolution'. Readers may refer to the IRRI Reporter No. 3/1976, which published the success story ('How Tongil Triggered a Korean Rice Revolution'; The IRRI Reporter No. 3/1976).

Reminiscences

My first participation to APWSS was in the 5th Conference held in Japan in 1975. Since then, I participated in APWSS Conference 12 times during the 50 years period. Although I am not familiar with the initiation of the APWSS in 1967, this has been documented by various authors, previously (Baltazar, 2007) and also by various Chapters in this Volume. I am also aware that the Editors have cast their eyes over the events that preceded the founding of our Society in 1967.

I believe that APWSS Conferences have been a most useful forum for exchanging information on how to fight against weeds in the region. With the Society, I understand that there was the proverbial growing pains and, like any growing child, the Society has had its share of moments of triumph and of despair. To me, however, the Society seems very much alive now, as in the past four decades, and useful in exchange of information on weeds and their control in the Asian-Pacific region.

Hosting an international conference in developing countries is difficult, because it needs a significant number of trained specialist who are committed to the task, and financial resources, as well as governmental support. The proportion of contribution of agriculture to a country's economy is also an important factor (see Chandrasena and Rao's review of Weed Science in the region, Chapter 1 of this Volume). If this contribution is relatively small, there is less interest in hosting Weed Conferences.

Thus, some countries like Australia, India, Indonesia, Japan, Malaysia, Philippines and Thailand, with well-established Agricultural or Weed Societies or Plant Protection Societies, hosted APWSS Conference two or three times each during the 50 years period. With the establishment of Weed Societies in Sri Lanka in late-1990s and Vietnam, in the early 2000s, these countries were also able to host APWSS Conferences (i.e. Vietnam in 2005; Sri Lanka, in 2007), both of which I was able to attend,

In addition to APWSS Conference, many types of seminar or symposiums were held in this region with publication of proceedings during the 1980-early 2000s, supported by international organizations such as FAO, IRRI and Food & Fertilizer Technology Center, National Weed Science Societies, Universities, and/or governments. Fortunately, I was able to participate in all the meetings except for one in held at Rome. Based on my experience, I strongly feel that these kinds of meetings were helpful for introducing new weed technologies, relevant to each country.

I wish to highlight the following activities, conferences and seminars, which were also held in the Asian-Pacific region, during 1970s-2003, and were important in exchanging Weed Science information:

- 'Weed Control in Rice' in 1983 (Conference held at IRRI, 31 August - 4 September 1981) financed by IRRI and IWSS. pp. 422.
- 'Weeds and Weed Control in Asia' (1981) financed by Food and Fertilizer Technology Center, Republic of China (FFTC Book series No. 20). pp. 1- 259.
- 'Integrated Management of Paddy and Aquatic Weeds in Asia' (1982); sponsored by the Food and Fertilizer Technology Center, Republic of China (FFTC Book Series No. 45). pp. 1-230.
- 'Improving Weed Management' (1982). Proceedings of the FAO/IWSS expert consultation on improving weed management in developing countries (FAO Plant Production and Protection Paper 44). pp. 1-185.
- 'Weeds and Their Control in Vegetable Production' (1987); supported by APWSS and Asian Vegetable Research & Development Center, and Food & Fertilizer Technology Center, Republic of China. pp. 1- 71.
- 'Weed Management of Asia and the Pacific Region' (1992); jointly organized and sponsored by FAO and Kyungpook National University (KNU), Daegu, Korea. Research Bulletin of Institute of Agricultural Science and Technology of KNU (Special Supplement 7). pp. 1-80.
- 'Biological Control and Integrated Management of Paddy and Aquatic Weeds in Asia' (1992); sponsored by the National Agriculture Research Center (NARC), Japan and Food & Fertilizer Technology Center, Republic of China (published in 1994). pp. 1- 442.
- 'Appropriate Weed Control in Southeast Asia' (1994); jointly organized and sponsored by FAO and CAB International (Eds. S.S. Sastroutomo& B. R. Auld). pp. 1-113.

- 'Weed Management in Rice' (1996). FAO Plant Production and Protection Paper 139 (Eds. B. Auld and K-U Kim), pp. 272.
- 'Herbicides in Asian Rice: Transitions in Weed Management' (1996) sponsored by Stanford University and IRRI (Ed. R. Naylor). pp. 1- 270.
- 'Biology and Management of Noxious Weeds for Sustainable and Labour Saving Rice Production' organized by National Agriculture Research Center (NARC) and Science & Technology Agency of Japan, and supported by Weed Science Society of Japan (2000). pp. 1-241.
- 'Challenges Today to Weed Management in 21st Century' (2001). Proceedings of International Symposium of the Weed Science Society of Japan. pp. 1-86.
- 'Weed Management for Developing Countries Addendum 1' (2003). FAO Plant Production and Protection 120, Add. 1 (Ed. R. Labrada). pp. 277.
- '*Echinochloa* Controlin Rice' (2001); sponsored by APWSS and FAO, Workshop held at Beijing. Proceedings published by FAO and KNU, Daegu, Korea in 2003 (Kim and Labrada, 2003).
- 'Management of Sedge Weeds in Rice' (2006); sponsored by APWSS and FAO, Workshop held at Ho Chi Min City, Vietnam. Proceedings published by FAO and KNU, Daegu, Korea in 2003 (Kim and Labrada, 2006).
- 'Utility of Weeds and Their Relatives as Resources' (2007). Monograph with contributions from all Asian-Pacific region countries. (Kim, *et al*., 2007). KNU, Daegu, Korea. pp. 222.

Most of key participants at the above meetings and activities were members of APWSS.I have no doubt that these proceedings and publications play an important guiding role for understanding of weed problems and control methods, being used in the Asian-Pacific region during 1980s and early 2000s.

Adding to my reminiscences, here I would like to reflect on my experiences serving as a Secretary of the Working Committee of 12th APWSS Conference (1989) held at Seoul, Korea. We communicated with more than 300 participants from overseas through mail or fax, unlike today's internet. Up until the participants in India in 2015 overtook this number, this was the biggest gathering of weed scientists and agronomists in APWSS's history.

A total of 589 delegates, from 21 countries were present; 198 papers were presented, and proceedings were published in four volumes. The highly successful meeting at Seoul was due tithe leadership of President Dr. D. S. Kim and the close cooperation and hard work of the Organizing Committee members, and support from chemical companies, and active participation of APWSS members. On behalf of Organizing Committee, once more, I would take this opportunity to express sincere thanks to all of APWSS members who helped us in Korea to host the event. Many of the current senior members of the APWSS and several of the contributors to this volume, were present at Seoul, as APWSS began to grow as an organization.

Role of International Organizations

IRRI, based in the Philippines, has played a very important role in the dissemination of weed technologies, particularly in rice, in the Asian-Pacific region. There were two great scientists- Dr. Surajit K. De Datta (Agronomist) and Dr. Keith Moody (Weed Scientist) at IRRI who were dedicated to improvement of weed control technology in the region. Another international organization is the FAO, based at Rome.

Since Dr. Ricardo Labrada assumed the Weed Officer position at the FAO in 1990, he has worked hard to promote the management of weeds across continents. In 1992, a 'Steering Committee for Weed Management for Asia and the Pacific Region' was organized by the FAO, with blessings from APWSS, and the 1st meeting was held at my own University - Kyungpook National University, Daegu, Korea. Appointed members of Steering Committee were Drs. Bruce A. Auld (Chairman, from Australia), Kil-Ung Kim (myself, as Secretary from Korea), H. S. Gill (India), Yang-Han Lee (China), H. Shibayama, and later Hirohiko Morita (Japan).

This Steering Committee meetings were held at different countries every two years to deliberate on many subjects. As scheduled, the 2nd meeting was held in Malaysia in 1994; followed by the 3rd meeting (Vietnam in 1996); 4th meeting (Thailand in 1998) and the 5th meeting (China in 2001).

The proceedings were published. FAO also supported the publication of a Newsletter twice a year for the Asian and the Pacific region covering weed-related information. Two important publications, 'Weed Management in Rice' (1996) and 'Weed Management for Developing Countries Addendum 1' (2003) seemed to be very valuable products of this Steering Committee, supported by FAO.

Conclusion

It is evident that farmers select methods that provide the desired degree of weed control at the lowest cost, and therefore, the costs of inputs are perhaps the most important factor, which determines input uses. Herbicide-based chemical control is the most commonly used method for weed control in developed counties; however, various other methods, rather than chemicals, are still being used on a large-scale in the least developed countries. Farmers in the developing countries struggle to buy and apply herbicides at the rates and application frequencies required to manage weeds effectively. However, the integration of herbicides into weed control programs, along with other innovations is important for the future.

The Biennial meetings of the APWSS has provided diverse information related to weed control, which are applicable across a range of crops and weeds. Thus, encouraging participation of developing country scientists at APWSS biennial meetings is one of the most desirable ways by which agriculturalists, extension officers, research scientists, academics and others can share all the new weed technology information presented by developed countries, as well as emerging economies.

At this moment, as we celebrate 50 years of APWSS's existence, my primary message is that international organizations like FAO, IRRI and FFTC, along with APWSS, should continue to play their role through organizing Conference, Workshops, Training Courses or Seminars, which can focus on solving immediate problems of developing countries related to weed control. Not to do so will put food production in the region at peril, as the population increases and land becomes scarcer.

Acknowledgement

I thank the Editors of this Volume, Drs. Nimal Chandrasena and A. N. Rao for producing this Celebratory Volume for future generations of weed scientists to appreciate how APWSS began and how it influenced the for the development of Weed Science in the region. I also wish to personally thank the main financial sponsor for this publication, my colleague Dr. Hirohiko Morita, and the 50th Anniversary Conference Organizers for this opportunity to share my thoughts with the readers.

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Fifty years of Asian-Pacific Weed Science Society and Indian Society of Weed Science: Reflections of History, Growth and Way Forward

A. R. Sharma[48]

Abstract

The Asian-Pacific weed Science Society (APWSS) and the Indian Society of Weed Science (ISWS) were born almost at the same time – APWSS in 1967; and ISWS in 1968 – to provide a platform for the Weed Science community to exchange ideas and promote the cause of Weed Science within their respective domains and jurisdictions. Both societies have progressed over the last five decades, contributing immensely towards the understanding of weeds and their management at both the national (respective countries) and international level.

While the APWSS is celebrating its Golden Jubilee this year in 2017, and organizing the 26th APWSS Conference at Kyoto, Japan (19-22 September, 2017), the ISWS will be celebrating the same next year and planning to organize an International Conference at the ICAR-Directorate of Weed research, Jabalpur. Indian weed scientists have actively participated in the activities of APWSS over the years, and in the past, organized the 8th APWSS Conference at Bengaluru in 1981; and the 25th APWSS Conference, at Hyderabad in 2015.

In view of the growing infestations of weeds and emerging challenges in weed management, there is an urgent need to further develop collaborations and partnerships for mutual sharing of knowledge and the advances made in the field of Weed Science, and develop appropriate approaches, as well as practical strategies to combat weeds, which continue to inflict heavy losses, in agricultural productivity, and are also implicated in damaging biodiversity, human and animal health, and environmental security.

Introduction

Weeds have been and will continue to a major biotic constraint for lowering agricultural productivity. The problems of weeds are as old as the agriculture itself, as almost all the crop plants have been domesticated from their wild relatives only. Primitive records show removal of weeds by hand and primitive tools. Later, during the period of 1000 BC, animal-drawn implements came into existence for removing weeds. During the first two to three decades of the 20th Century, mechanically powered implements like cultivators, hoes and weeders were invented, developed and used for weed control purposes.

The history of modern Weed Science research started way back in 1908, when the selective action of copper sulphate as a herbicide was recognized. The revolution in chemical weed management occurred with the discovery of 2, 4-D and its field application in the 1940s. Prior to that, not much attention was given towards Weed Science as multi-disciplinary branch of agriculture. Although this 'Science' is still

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not very much advanced in developing countries, spectacular progress has been made in the developed world through scientific research, as evidenced by the availability of the wide array of herbicides and technology for weed management.

In India, chemical weed control began in the pre-independence era in the Punjab State, when sodium arsenate was first used to control *Carthamus oxyacantha*. In 1948, 2, 4-D was introduced to India, and since then, many herbicides have been introduced for controlling weeds in different crops. Herbicides belonging to triazines, ureas and phenoxy compounds were first tested in 1950s at Tocklai Tea Experimental Station, Jorhat (Assam). The Indian Council of Agricultural Research (ICAR) sanctioned several schemes for testing the field performance of herbicides in crops like rice, wheat and sugarcane. The States covered in this programme included Tamil Nadu, West Bengal, Punjab, Maharashtra, Andhra Pradesh, Rajasthan, Kerala, Madhya Pradesh, Uttar Pradesh, Jammu and Kashmir, and Assam.

The main objective of this scheme was to survey the weed flora of a region in the major crops and investigate the relative efficiency of herbicides and economics of their use in terms of increase in yield; and their superiority or otherwise, over manual and mechanical weed control methods. In the 1960s and 1970s, Agriculture Departments of the States, Agricultural Universities and ICAR Institutes carried out research with a numbers of herbicides, despite some chemicals being unavailable commercially in India. However, surveying weed flora and testing of herbicides for individual crops remained the main focus of research for about 25 years until 1978. Follow-up action to these initiatives were slow, as State Governments did not realize the importance of weed control, with or without herbicides, in increasing agriculture production in the country. In fact, the use of herbicides for weed management found its momentum only aroundmid-1970s, when the farmers of Punjab and Haryana began using herbicides, particularly in rice and wheat.

With the modest progress of Weed Science, a conference was held in 1977 at Hyderabad to review the advances made in Weed Science and define future work priorities to meet the new challenges of increasing food production. It was also aimed at developing a Weed Science curriculum in Agricultural Universities. Recommendations made by the Workshop in the curricula for B.Sc. (Ag.), M.Sc. (Ag.) and Ph.D. levels were accepted by many Agricultural Universities and future directions given for Weed research were adopted by many researchers working in different ICAR Institutions and other organizations.

However, as a discipline, Weed Science was slow to develop in India, until late-1970s. The field lacked trained personnel to carry out studies on various aspects of Weed Science, viz. weed biology and ecology, herbicides physiology, residue estimation and management, herbicide application devices, adjuvant and antidotes etc. The research programme on weed control, however, was strengthened through the All India Coordinated Research Project (AICRP) on Weed Control through a negotiation between ICAR and US Department of Agriculture (USDA). Initially, six centres were started at different State Agricultural Universities; this has now grown to 23 centres, located in different States of India and Agricultural Universities. Over the last four decades, this project has assisted the farming community through the transfer of scientific knowledge, technologies and tools to effectively reduce yield losses due to weeds in crops.

During the period from 1984 to 1992, the annual workshops of the AICRP–Weed Control and the biennial conferences of the Indian Society of Weed Science were organized to review the progress of research done during the preceding years on different aspects of weed science and to work out the technical programme for the ensuing years. The emphasis, however, was given to compiling the work done as weed survey in various agro–climatic zones, integrated weed management in different crops/cropping systems and intercropping systems, studies on biology and control of problem weeds, herbicide residue estimation and management, physiological aspects i.e. allelopathic effect of weeds on weed and crops, and to design and develop different types of weed control tools/implements, spraying equipment, power-operated aquatic weeders, etc.

A number of training programmes were also arranged to impart training in herbicide residue estimation. One joint workshop, i.e. Indo–Pak–US Workshop was arranged at the Agricultural Experimental Station, Jaipur, during 1986; and another, at Pakistan Agriculture Research Council, Islamabad, in 1987, with the assistance from FERRO (Far Eastern Regional Research Office), USDA (US Department of Agriculture). These programmes stimulated interactions between scientists in India and other countries and improve the research agenda in Weed Science, which aimed to develop best and appropriate technology for the country.

These deliberations led to planning to establish a National Centre for basic, as well as applied research in Weed Science. Accordingly, the National Research Centre for Weed Science (NRCWS) came into being in 1989 at Jabalpur[49] in Madhya Pradesh (M.P.). Now this centre has been upgraded as Directorate of Weed research (DWR) and has developed as a modern institute, fully-equipped with all the facilities for high quality research, training and extension in Weed Science.

Weed Science in the Asian-Pacific region and some major issues

The Asian-Pacific region accounts for the bulk of the global agricultural production, contributing 95% of tea, 80% of rice, 70% of pulses, 40-60% of wheat and maize, 30% of soybean and sorghum, and over 95% of spices and herbs. This region, with both tropical and temperate climates, is also home to world's most diverse weed flora, growing in a wide range of crops. The region also has all of the 10 World's Worst Weed species, in addition to hundreds of other annual and perennial weeds, infesting croplands and aquatic systems, adversely impacting agriculture, economy and the environment.

The practices of cultivation of crops and weed infestations are largely similar in most countries of the Asian-Pacific region, where there are similarities in climate, geography and agricultural practices. Weeds associated with rice may vary to some degree with the country, method of rice establishment, the rice cultivar grown, management practices used and the environment. In the case of rice, the extent of yield losses caused by weeds depends on the weed species present; their abundance and level of dominance and associated environmental factors. Estimates at global level indicate that weeds in rice account for 48.2% of potential losses and 27.3% of actual losses caused by all pests together. Hence, weed management plays a critical role in realizing the much-needed increase in rice production in the Asian-Pacific region.

Manual weeding, alone or in combination with other methods, is still the most predominant method of weed removal in many countries in the Asian-Pacific region. However, it is not only tedious, time-consuming and inefficient, but is increasingly becoming uneconomical as well. Wage rates for farm workers in South East Asia have steadily increased; the average wage rate today is 5-10 times greater than what was prevalent in the 1970s. For example: in India the wages were less than \$0.5 in 1970s, are currently range from \$4 to \$5 per person per day. In other words, a single round of hand weeding of one ha

[49] http://www.dwr.org.in/About_Us.aspx

rice, which used to cost $10, costs now a minimum of $80. Poverty alleviation programmes, introduced in some countries to promote inclusive growth in economy have also contributed to the scarcity of labour for farm work. The use of draught animals for inter-cultural operations is also declining, due to costs. Cono weeders, power tillers and weeders are also used in row wet-seeded and transplanted rice in India and other developing countries. Hiring of these machines is a common practice, although many thousands of farmers struggle to afford such costs.

Herbicides have increasingly been substituted for manual and mechanical weeding, due to increase in farm wages and government policies. The projections are to expect 100-200% increases in the current labour price within 5-10 years. Farmers are therefore left with little choice, but to reduce labour and production costs, particularly for the most labour-intensive tasks, such as manual weeding.

Studies by scientists in Bangladesh revealed that pre-emergence herbicides in rice are 40-50% cheaper than one hand weeding, and herbicide applications gave 116% higher net income than hand weeding, because of the increased yield and lower costs of weed control. In China, the area treated with herbicides has increased from <1.0 m ha in the early 1970s to >60 mha in 2000. Rice accounted for 17% of total herbicides used in India in 2010. In Malaysia, weed management is herbicide-based and about US$4.10 million is spent annually on herbicides for rice alone, and this amounts to approximately 7% of the total expenditure on herbicides as per reports in 2004, which might have increased further by now.

In the Philippines, 96-98% of rice farmers use herbicides with the majority of farmers supplementing herbicide application with hand weeding. In Pakistan, about 20% area in rice is treated with herbicides. In Korea, the rice area treated with herbicides was 27% in 1971, 65% in 1977 and currently entire area is treated with herbicides. A similar trend of increasing use of herbicides in rice production has been observed in Vietnam. In sharp contrast, in Nepal, 91% of rice farmers are still reported to be practicing, labour-intensive, manual weeding and only about 2% reported to have used butachlor.

Herbicides have been and will continue to be the major tool for managing weeds in the Asian-Pacific region. However, continuous use of herbicides have resulted in the incidences of resistant weeds, which is more in developed countries like Australia and USA, where herbicides have been in use for long. Among crops, wheat and rice have more herbicide-resistant weeds than maize. In developing countries of the Asian-Pacific region also, the shift in methods of rice establishment to direct-seeding rice (DSR), has increased herbicide use. However, the continuous use of the same herbicide season after season, has resulted in weeds in rice developing resistance to herbicides. For preventing the development of herbicide resistance in weeds, best management practices have been suggested, which needed to be popularized among farming communities. These include not just rotation of herbicides, using herbicides of different modes of action, but also their better integration with cultural practices.

Weedy rice is becoming a threat in rice and especially in direct-seeded rice fields of Asian-Pacific region and it needs special attention by researchers to prevent its spread and effectively manage, in each of the country of Asian-Pacific region. Clearfield rice – an imidazolinone resistant rice derived from conventional breeding technique, has been in cultivation in Malaysia mainly for managing weedy rice. It is under testing stage in Vietnam. The possible evolution of resistance to ALS-inhibitor herbicides in weedy rice and the risk of weedy rice acquiring resistance to herbicides following introgression of resistant gene from the HT rice are the major concerns that need to be addressed adequately. Educating rice farmers is essential prior to the release and popularization of genetically/conventionally modified rice varieties tolerant to herbicides.

Indian Society of Weed Science (ISWS)

With growing interest in weed research, the ISWS was founded in 1968 at the Haryana Agricultural University, Hisar by the collective efforts of many scientists to advance the development of weed science in India. Some individuals like Dr. M. K. Moolani and Dr. H. R. Arakari, took active interest in weed control and contributed towards the early development of Weed Science in the country.

The establishment of ISWS coincided with the green revolution in the country. The Society began publishing its journal 'Indian Journal of Weed Science' from 1969. Initially, the Headquarters of the Society was at Hisar, and then moved to Bangalore for nearly a decade (1980-1992). The Headquarters of the society was again shifted to Hisar, and remained there, until 2005. Following the establishment of National Research Centre for Weed Science (now named, as Directorate of Weed Research, DWR,) in 1989 at Jabalpur, the Headquarters of the Society was finally shifted to Jabalpur in 2006.

The objectives of ISWS are: (i) To promote the knowledge of weed science and allied branches, (ii) To encourage research in the scientific and practical aspects in different disciplines of weed science, (iii) To provide opportunity through periodical meetings and scientific conferences for personal contacts and discussions for the research workers in the field of Weed Science, and (iv) To publish periodically scientific articles contributed by members and/or eminent scientists in the field of Weed Science in the country and abroad.

The ISWS brings out various publications, including the Indian Journal of Weed Science (quarterly), ISWS Newsletter (six monthly), Proceedings of Conferences, books, monographs etc. The Indian Journal of Weed Science has been published continuously, since 1969. The Society has also been honouring weed scientists of the country and abroad, in recognition of their professional leadership, outstanding contributions and services to the ISWS. The Society has organized various national and international conferences, meetings, and workshops on emerging issues in Weed Science. The details of various conferences organized in the last 25 years are given in Table 1.

Asian-Pacific Weed Science Society

The Asian-Pacific Weed Science Society was founded on 22 June, 1967 in the Hawaiian island of Kauai. A series of events, brought about by the vision, planning, and hard work of the APWSS founding fathers led to this momentous occasion. In January 1967, Dr. William R. Furtick, Professor at Oregon State University, Dr. Roman R. Romanowski and Dr. Donald L. Plucknett, both Professors at University of Hawaii, realizing the need to establish linkages with fellow weed science workers in the Asia-Pacific region, met and discussed what should be done in weed science in this part of the world. Out of that meeting and brain storming session, the first "*Asian-Pacific Weed Control Interchange*" was organized and held on 16-22 June, 1967 at the University of Hawaii in Honolulu during the first week and in the island of Kauai during the second week. The meeting, attended by about 87 delegates from 22 countries, was co-sponsored by the East-West Center Institute for Technical Interchange and the University of Hawaii.

On the last day of the Interchange, the delegates met at the Prince Kuhio Hotel in the island of Kauai, and organized the Asian-Pacific Weed Science Society. The first set of officers were elected, with Dr. Marcos Vega as President and Dr. Roman Romanowski as Secretary. Dr. Don Plucknett was elected Secretary in 1969 and was in that role for 14 years, but continued to support the Society in many ways over a long period. The theme for that first Conference, held under the chairmanship of Dr Marcos Vega of Philippines, was "Weed control - basic to agricultural development" and how true it remains until today. Since that first meeting, sparked by the vision, enthusiasm and hard work of our founding fathers and the various APWSS officers and members, weed scientists, and individuals in the Asian-Pacific region who have devoted their time, efforts, and energy to the Society over almost 50 years, the APWSS has grown and developed into a major regional and international weed science society.

Table 1: Biennial Conferences organized by the ISWS during the last 25 years

No.	Conference	Date	Venue	Theme
1	International Symposium	18-20 November, 1993	Haryana Agricultural University (HAU), Hisar	Integrated weed management for sustainable agriculture
2	VI Biennial Conference	9-10 February, 1995	Annamalai University	-
3	VII Biennial Conference	19-21 February, 1997	PAU, Ludhiana	-
4	VIII Biennial Conference	5-7 February, 1999	BHU, Varanasi	-
5	IX Biennial Conference	23-24 May, 2001	UAS, Bangalore	Eco-friendly weed management options for sustainable agriculture
6	X Biennial Conference	12-14 March, 2003	GBPUAT, Pantnagar	-
7	XI Biennial Conference	6-9 April, 2005	PAU, Ludhiana	-
8	XII Biennial Conference	2-3 November, 2007	HAU, Hisar	New and emerging issues in weed science
9	XIII Biennial Conference	5-7 February, 2008	BVC, Patna	Recent advances in weed research
10	XIV Biennial Conference	25-26 February, 2010	IGKV, Raipur	Recent advances in weed science research
11	National Symposium	21-22 August, 2010	NASC, New Delhi	Integrated weed management in the era of climate change
12	XV Biennial Conference	19-20 April, 2012	KAU, Thrissur	Weed threat to agriculture, biodiversity and environment
13	XVI Biennial Conference	15-17 February, 2014	DWSR, Jabalpur	Emerging challenges in weed management
14	XVII Biennial Conference	1-3 March, 2017	MPUAT, Udaipur	Doubling farmers' income: The role of weed science

The general objective of APWSS is to promote weed science, in particular in the Asian-Pacific regions, by pooling and exchanging information on all aspects of weed science. The primary objective during the first meeting was to facilitate the interchange of current weed control information and to promote research in weed science in the Asian-Pacific region, because during those periods, most research in weed control had been confined to the temperate zone. To be able to achieve the initial objectives, Dr. Don Plucknett, one of the founding fathers, aimed to identify: (a) the weed workers in the Asian-Pacific region; (b) the major weeds and weed problems; (c) the research and development needs of various countries in the region; and (d) the linkages necessary or possible in dealing with the perceived needs.

The Society has delivered extensively on its prime objective of promoting weed science in the Asian-Pacific region, by pooling and exchanging information. This has been done primarily through its biennial conference held regularly in different locations. The effort has been enhanced through occasional workshops and symposia, held as necessary, which brought together many experts including some from out of the region. Two famous books, "The World's Worst Weeds" and "A Geographical Atlas of World Weeds" have been co-authored by APWSS founding members (Leroy Holm, Juan Pancho, Donald Plucknett and Horace Clay) with support from APWSS and the East-West Centre at the University of Hawaii. The international journal 'Weed Biology and Management', first published in March 2001, (and now in its 17th year) is published by the Weed Science Society of Japan with, and encouragement from, various national weed science societies affiliated with APWSS.

Over the years, the discipline of Weed Science has developed in many countries of the region and professional societies dealing with the subject have been established for mutual exchange and sharing of knowledge. Besides organizing various activities including conferences and symposia at the national level, these professional societies have also been providing a platform for sharing of international experiences on emerging issues in weed science. The APWSS has been providing a major platform for these regional Weed Science Societies for organizing the APWSS Conferences every two years. Over the years, these Conferences have been organized in different countries of the Asian-Pacific region, as given in Table 2.

Although scientists from about 20-25 countries have participated in these Conferences, Weed Science Societies of only 16 countries have been established, which are affiliated to the APWSS.The number of participants attending each conference increased from the 87 founding members in 1967 to about 300 in the 1980s, peaking at 690 in 2015. The number of papers also increased from 50 in 1967, peaking at 760 in 2015. The quality of Conference proceedings has also improved substantially, with some Conferences producing two large volumes.

The 25th APWSS Silver Jubilee Conference, Hyderabad, India

The Silver Jubilee Conference of the APWSS on the theme "*Weed Science for Sustainable Agriculture, Environment and Biodiversity*" was organized during 13-16 October, 2015 at the Professor Jayshankar Telangana State Agricultural University (PJTSAU), Hyderabad, India. This mega event was organized by the Indian Society of Weed Science (ISWS) in collaboration with the Indian Council of Agricultural Research (ICAR) and Directorate of Weed research (DWR), Jabalpur. The Conference was attended by 690 registered participants including 107 from overseas and 46 from industries.

At this Conference, 11 plenary presentations were made by stalwarts in Weed Science who had made a mark at the international level. In all, there were 12 technical sessions in which 16 lead presentations and 106 oral presentations were made. There were five satellite symposia on emerging topics, viz. Weed Management in Conservation Agriculture; Weedy Rice Challenge in Asia: Issues and Options for Management; Herbicide Resistance: Current Status and Future Challenges; Biological Control – progress an future prospects in the Asia-Pacific region; and Utilization of Weeds as Bio-resources. Apart from these, 627 poster presentations were made during the Conference.

Table 2: Details of Conferences of APWSS held during the last 50 years

No.	Date	Venue	Theme	No. of Papers	No. of Delegates	No. of Countries
1st	12-22 June, 1967	Honolulu, Hawaii, USA	Weed science basic to agricultural development	50	87	22
2nd	16-20 June, 1969	Los Banos, Philippines	-	47	146	20
3rd	7-12 June, 1971	Kuala Lumpur, Malaysia	-	74	200	20
4th	12-16 March, 1973	Rotorua, New Zealand	-	78	300	18
5th	5-11 October, 1975	Tokyo, Japan	Integrated control of weeds	114	308	21
6th	11-17 July, 1977	Jakarta, Indonesia	Weeds in small scale farms	105	314	22
7th	26-30 Nov., 1979	Sydney, Australia	Weeds in urban bushlands	134	311	18
8th	22-29 Nov. 1981	Bangalore, India	Perennial weeds in cropped lands &unwanted vegetation in non-cropped lands	120	311	18
9th	28 Nov –2 Dec. 1983	Manila, Philippines	Weed control in cropping systems	83	305	20
10th	24-30 Nov. 1985	Chiang Mai, Thailand	Weeds and the environment in the tropics	117	530	23
11th	29 Nov. -5 Dec. 1987	Taipei, Taiwan, China	Weeds and their control in vegetable production	144	462	17
12th	21-16 August, 1989	Seoul, South Korea	Weed problem and their economic management in Asian-Pacific Region	198	589	21
13th	15-18 Oct. 1991	Jakarta, Indonesia	Vegetation management strategy for sustainable development	96	199	16
14th	6-10 Sep. 1993	Brisbane, Australia	Weed management – towards tomorrow	114	453	18
15th	24-28 July, 1995	Tsukuba, Japan	Innovative weed management strategies for sustainable agriculture	182	450	20
16th	8-12 Sep. 1997	Kuala Lumpur, Malaysia	Integrated weed management towards sustainable agriculture	140	375	27
17th	22-27 Nov. 1999	Bangkok, Thailand	Weeds and environmental impact	223	392	21
18th	28 May-2 June, 2001	Beijing, China	The role of ecologically-based weed management for sustainable agriculture in the 21st Century	201	400	26

No.	Date	Venue	Theme	No. of Papers	No. of Delegates	No. of Countries
19th	16-21March, 2003	Manila, Philippines	Weed science, agricultural sustainability and GMOs	143	200	20
20th	7-11 Nov. 2005	Ho Chi Minh City, Vietnam	Six decades of weed science since the discovery of 2,4 D	111	258	23
21st	2-6 Oct. 2007	Colombo, Sri Lanka	Weed science for sustainable development in the 21st century	134	189	19
22nd	March, 2010	Lahore, Pakistan	Judicious weed management – road to sustainability	112	-	9
23rd	26-29 Sep. 2011	Cairns, Australia	Weed management in a changing world	140	210	26
24th	22-25 Oct. 2013	Bandung, Indonesia	The role of weed science in supporting food security by 2020	105	112	16
25th	13-16 Oct. 2015	Hyderabad, India	Weed Science for sustainable agriculture, environment & biodiversity	760	690	25

Celebrating the Silver Jubilee of the APWSS Conferences, a book release was held on 14th October, 2015, which was another unique event of this Conference. On this occasion, a special publication on "Weed Science in the Asian-Pacific Region" edited by V. S. Rao and a team of APWSS Scientists was launched (Rao *et al.*, 2015). This publication offers a unique opportunity for global weed scientists in contextualizing weed problems across the region and sharing information on best weed management practices.

This is probably the first effort of its kind to compile information on the status of a given discipline of agricultural science in the select countries of a region. This 389-page book has 19 chapters, contributed by 47 weed scientists from 19 countries, providing a wealth of information on the status of Weed Science in the countries of the region on different aspects. These include the major weed species in crop and non-crop systems; invasive and parasitic weeds; innovative strategies in weed management; herbicides; allelopathy and allelochemicals; bio-herbicides and bio-control agents. The book also covered herbicide application; herbicide-resistant weeds and their management; herbicide-resistant biotech crops, adoption, benefits and concerns; as well as the potential applications of omics and genomics for better weed management.

Special attention has also been paid to highlight the needs for expanding the research agenda, education, extension and training in Weed Science, herbicide industry; emerging concerns and the future outlook on developments in Weed Science.

Emerging challenges and concerns

Weed problems are dynamic in nature and are likely to be more serious in the coming decades, due to the following factors: (i) adoption of dwarf HYVs and hybrids, (ii) high-input agriculture, (iii) altered agronomy – zero-till, organic farming, (iv) monoculture cropping / fixed cropping systems, which cause shifts in the weed floras, (v) development of herbicide resistance in weeds, (vi) herbicide residue hazards,

(vii) growing infestation of weedy rice, parasitic and other obnoxious weeds, (viii) globalization and invasion of alien weeds, (ix) implications of climate change, and (x) lack of quality human resources in Weed Science. Various stakeholders express serious concerns about weed management in real field situations. In fact, weed related problems are one of the most common issues for discussion at meetings, seminars, trainings, workshops, etc. in India.

With regard to weed-related matters in India, the following issues are common concerns raised by stakeholders: (i) non-availability of labour for weed control, (ii) rising costs of manual weeding, (iii) invasion of new weed species, (iv) application techniques of herbicides, (v) herbicide + other pesticide combinations, (vi) non-availability of herbicides and mechanical tools, (vii) spurious chemicals, costly herbicides, (ix) large-size packages of herbicides, (x) registration of new molecules, (xi) lack of awareness / extension efforts, and (x) weeds in no-man's lands (i.e. public spaces, not well maintained by agencies and governments).

Continuous refinement of weed management technologies is essential to cut down production costs, and also in the light of ever-changing socio-economic conditions of the farmers and international trade policies. Rapid expansion of weedy rice infestation, evolution of herbicide-resistant weeds, introduction of alien invasive weeds, lack of low-cost environment-friendly weed management technologies for water bodies and for dryland farming systems are some of the burning issues requiring immediate attention. Herbicides are going to become increasingly popular in the coming years but the residue hazards and other environmental issues are also required to be suitably addressed. Development of suitable technologies to tackle the probable scenario that may emerge in the area of crop-weed competition due to increasing atmospheric CO_2 concentration and subsequent global warming are some of the major future challenges. Herbicide-tolerant GM crops may be a possibility in Indian agriculture in near future.

In India, a great deal of change has occurred in weed management in the last few decades. In fact, serious research in Weed Science began to be undertaken in our country only during 1970s when some herbicides like 2, 4 D, butachlor, isoproturon, atrazine and a few others were found highly effective in major cereal crops. Some weeds in croplands and non-crop lands started becoming predominant in the 1990s, for which, effective control measures were developed. Studies on herbicide use in other crops like pulses and oilseeds were started with the availability of new herbicide molecules. Thereafter, issues related to herbicide residues and resistance development in weeds cropped-up and systems approach to weed management was emphasized. Aquatic weeds also gained attention due to their vast invasion in the water bodies. In the present times, low-dose high-potency herbicide molecules and mixtures have become available for major crops like rice, wheat and soybean. It is also feared that climate change will shift the behaviour of crop-weed competition. However, newer opportunities will also be available in the coming decades for tackling weed menace with the adoption of conservation agriculture, organic farming and precision farming systems.

A holistic approach with multi-disciplinary, multi-locational and multi-institutional involvement would be imperative to tackle future weed problems. More emphasis will be given on developing integrated weed management technologies involving non-chemical methods, use of cover crops, weed suppressing crop cultivars; mechanical weeding tools, etc. Basic research in areas like allelopathy and bio-herbicides which have relevance for practical weed management will be undertaken through collaborative arrangements with other organizations. Research on biological control of important alien invasive weeds in non-cropped situations, aquatic bodies, etc. with the participation of all stakeholders and on-farm research in participatory mode and take part in technology development, refinement and transfer is needed. Technologies developed will be refined and fine-tuned for their suitability in actual farmers' situations through on-farm trials, awareness campaigns, farmers' fair, farmers' training, etc. The involvement and partnership of other line departments such as state departments of agriculture, NGOs, local administration, etc. will be ensured to achieve the goals.

The sound technical programme for network research on management of aquatic and parasitic weeds, weed management in rainfed agriculture, horticultural and vegetable crops will be required after thorough interaction with collaborating organizations. Emphasis is needed to develop infrastructures like phytotron growth chambers, containment facilities and large-sized open top chambers with controlled CO_2, temperature and humidity components for climate change related studies, sophisticated laboratory facilities for molecular biology works, quarantine facilities for Weed Risk Analysis.

APWSS: Way forward

As celebrated in this Volume, the APWSS has played an extremely important role by connecting people from so many parts of the world and providing a vibrant forum for the exchange of Weed Science information. It has now become the largest regional Weed Science Society in the world. In my opinion, the APWSS can strengthen Weed Science in the region by way of the following: (i) organising and facilitating regional workshops on specific topics, (ii) supporting publishing of special issues of the journal Weed biology and Management to deal with specific areas, (iii) formulating and encouraging networks for widespread problems such as weedy rice and herbicide resistance, (iv) linking up young weed scientists with the industry and internationally recognised institutions, (v) providing advocacy for adequate education and research grants in weeds science, and (vi) be at the forefront of identifying emerging issues of weeds and creating opportunities for employment of long-term solutions to weed problems.

For achieving this, the Society needs to broaden its horizon and strengthen itself scientifically, as well as financially. A permanent and continuing committee involving committed representatives from the member countries is needed to take the activities of the Society forward. Unfortunately, the financial position of the Society is not very sound, due to which it is not in position to sponsor activities and increase its visibility. It is therefore essential that the individual members and the national weed science societies contribute a reasonable share out of their earnings towards the APWSS. The Indian Society has already made a beginning in this regard by contributing 10% of the registration fee at the 25th APWSS Conference held at Hyderabad in 2015. It is hoped that others will follow this example set by the ISWS in the coming years.

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Reflections on the Indonesian Experiences and the future of APWSS

Denny Kurniadie[50]

It is with pleasure that I accept the invitation from the Editors of this Volume to send this congratulatory message to the Asian-Pacific Weed Science Society in its celebrations of 50 years of existence. I wish to offer the following reminiscences and reflections and share my thoughts in this Celebratory Volume.

I have been involved in Weed Science for a long time, and became a member of Weed Science Society of Indonesia (WSSI) in 1993. I was elected General Secretary of this Society for two election periods, during 2004 to 2010. Following this, I was elected as the President of this Society from 2010 until the present. I got to know about the Asian-Pacific Weed Science Society (APWSS) from a colleague in the Faculty of Agriculture Padjadjaran University in Bandung Indonesia.

I believe that Indonesia was a very strong and pioneering member of the APWSS at the beginning in 1967. Indonesia took such a central role in those early years that, after the first 10-years of APWSS existence, Indonesia organized the 6th APWSS Conference during 11-17 July, 1977. Dr. Mohamad Soerjani, President of APWSS (1975-1977) led the Conference, which also produced the first Commemorative Volume, entitled "Commemorating 10 Years, 1067-1977, Asian-Pacific Weed Science Society".

The previous President of Weed Science Society of Indonesia Dr. Soekisman explained the history of the APWSS and how the 13th APWSS Conference was held in Jakarta, Indonesia during 15-18th October, 1991. He was also expecting me, as the Chairman of WSSI, to undertake the hosting of the APWSS Conference once again in Indonesia. Dr. Soekisman, who had been APWSS Country Representative for many years, explained that it would be an honour if Indonesia was elected again to be the host of the 24th APWSS Conference.

I searched the APWSS through the Internet, and finally understood what activities APWSS undertook, within Weed Science. While I was searching, in 2011, the 23rd of Asian Pacific Weed Science Society (APWSS) Conference had been announced, to be held at Cairns Australia. Immediately, I became interested to attend the Cairns Conference, and submitted my paper. However, due to a limited budget and high cost of the registration fee and accommodation in Australia, I could not come attend the Conference.

One of my intentions in attending the Cairns Conference in Australia was to bid for hosting the 24th APWSS Conference in Bandung Indonesia. Fortunately, Dr. Steve Adkins, as the President of the APWSS, during the period of 2010-2012 gave us the opportunity to bid for hosting the 24th APWSS conference through Internet. I understand that our bid was presented as a Power Point presentation by Dr. Adkins, and there were no other, clear bids, although India and Bangladesh showed an interest, but did not proceed with their bids. As a result, the Indonesian bid was accepted, and finally, my dream became true! I was elected as the APWSS President to undertake the responsibility of hosting the APWSS Conference at Bandung, Indonesia in October 2013.

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At this 24th APWSS Conference, I had a dream that people from developing countries who had limited budgets would be able to come. The registration fee for the 24th APWSS Conference in Indonesia was range between US $ 85 and US $ 135, and I believed this fee would be one of the cheapest registration fees for a major, International Conference, such as the APWSS. As a comparison, the registration fee for the 23rd APWSS held at Cairns, Australia, was about US $ 650 – US $ 800; and for the 25th APWSS Conference in Hyderabad, India, it was US $ 350.

Even if the registration fee was such a low figure, many interested people asked for a further reduction. There were 119 participants at the Conference, among them, there were 56 people from Indonesia. Most others were from India (largest contingent after Indonesia), Australia, New Zealand, Japan, Pakistan, Bangladesh, Malaysia, USA, Thailand, Vietnam, Philippines, South Korea, China, Sri Lanka and Taiwan.

Based on our evaluation of participants, most of them were satisfied with the Conference program. The topics of the Conference and also keynote speakers were also evaluated as quite good. Most of Indonesian participants did not know about the APWSS or its program; so, it is necessary for APWSS in the future to be more active in promoting Weed Science-related activities through all Country Representatives.

I also do hope that the APWSS in the future will not only conduct the Conference every two years, but also publish a scientific journal. I was wondering that APWSS could be like the Weed Science Society of America (WSSA), which publishes Weed Science and Weed technology journals.

It would also be good if the APWSS in the future has a book donation program (Weed Science books) to the developing countries. I hope also the registration fee in the future APWSS Conferences will not be too high, or, at least, there will be a special, discounted fee for participants who come from developing countries.

I wish APWSS every success in the future, and will be closely involved, as a representative from Indonesia.

Acknowledgement

I thank the Editor, Dr. Nimal Chandrasena for providing additional information on APWSS's past history, making valuable suggestions on the contents of my paper and for improving this manuscript.

Reminiscences of the 20th Asian-Pacific Weed Science Society Conference held in 2005 in Vietnam

Dr. Duong Van Chin[51]

It is a great honour for me to be given the opportunity to send this congratulatory message to the Asian-Pacific Weed Science Society in its celebrations of 50 years of existence. I was privileged to be the APWSS President during 2003-2005, which culminated in Vietnam hosting the 20th APWSS Conference. With gratitude and pleasure, I offer the following reminiscences and reflections for the Celebratory Volume.

Vietnam and the APWSS

I was functioning as a Weed Scientist of the Cuulong Delta Rice Research Institute (CLRRI), Ministry of Agriculture and Rural Development of Vietnam (MARD), when I put forward the proposal at the 17th Asian-Pacific Weed Science Society Conference, 1999 at Bangkok, Thailand, for Vietnam to host the 19th APWSS Conference, in 2003. Our objective was to create an increased awareness on the importance of Weed Science in crop production in Vietnam among weed scientists, in particular, and agricultural scientists, in general.

I obtained my wn M.Sc. and Ph.D. in Weed Science, within Agronomy, at the Indian Agricultural Research Institute (IARI), New Delhi, India. On returning home in 1992, I continued work on Weed Science and farming systems at the CLRRI. I was also able to attend the 15th APWSS Conference, at Tsukuba, Japan in 1995; and the 16th APWSS Conference, at Kuala Lumpur, Malaysia (1997). My proposal to hold the 19th APWSS Conference in Vietnam was rejected by the APWSS Executive Committee at the 17th APWSS Conference, at Bangkok, Thailand, because, at that time, Vietnam did not have National Weed Science Society.

On returning from the 17th APWSS Conference, I made efforts to contact related organizations, such as the National Plant Protection Institute (NPPI), Vietnam Biology Association, Cuulong Delta Rice Research Institute (CLRRI) of MARD, Can Tho University and other institutions and impress upon them to form an organization. As a result, the Vietnam Weed Science Society was formed in 2000 at the first Convention in Can Tho City, in the Mekong Delta of Vietnam. Associate Professor Dr. Nguyen Van Tuat, myself and Mr. Nguyen Van Thai were elected as the President, Vice President and Secretary of the Vietnam Weed Science Society (VWSS), respectively.

When I attended the 18th APWSS Conference at Beijing, China, and presented our proposal to organize the 20th APWSS Conference in 2005 in Vietnam, this was approved by the APWSS Committee, led by Dr. Ze Pu Zhang. The proposal team, led by myself, were delighted and went into action almost immediately, forming a Local Organizing Committee, and an International Advisory Committee. An extremely busy period ensued.

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20th APWSS Conference, Ho Chi Min City, Vietnam, 2005

The 20th APWSS Conference was held during 7-11 November 2005 at the Rex Hotel in Ho Chi Minh City, Vietnam, and was organized byte 20th APWSS Organizing Committee and the CLRRI.

Co-organizers were: VWSS, PPD (Plant Protection Department of MARD), and agricultural chemical companies, such as: BASF, Dow AgroSciences, Kumiai Chemical Industry, Monsanto and Syngenta. Additional supporters were: HAI Agrochem Joint Stock Company, International Inspection-Fumigation JSCo., LG Life Sciences Ltd, and Saigon Plant Protection State Limited Company.

The Executive Committee of the APWSS (2003-2005) had the following members: President - Dr. Duong Van Chin (Vietnam); Vice President - Dr. B. Marambe (Sri Lanka);General Secretary - Dr. Tran Thi Ngoc Son (Vietnam); Treasurer - Dr. Steve Adkins (Australia); Newsletter Editor - Dr. Yasuhiro Yogo (Japan); and Former President - Dr. Aurora M. Baltazar (Philippines). The Local Organizing Committee had 31 members, led by the Chairman (Dr. Duong Van Chin) and Vice-Chairman (Mr. Nguyen Huu Huan). The twelve members of the Advisory, International Committee hailed from several countries, including Vietnam, Australia, USA, Korea, Malaysia, India and Japan.

There were 111 research papers published in the 20th APWSS Proceedings with eight of them in the Plenary Sessions. The remaining technical papers were presented in 12 concurrently-held sessions, under the themes: (i) history of Weed Science, (ii) weed biology and ecology, (iii) varietal improvement, (iv) allelopathy, (v)herbicides, (vi)biological control, (vii) herbicide resistant weeds and crops, (viii) integrated weed management, (ix)biodiversity and plant extinction, (x)utilization of weeds, and (xi) education and technology transfer.

We chose the theme of the 20th APWSS Conference to be: "*Six decades of Weed Science since the discovery of 2, 4-D (1945-2005)*". This theme was chosen to remind allseed scientists of the region how significant has been the contribution of the first selective organic herbicides (discovered in 1944-45) in changing the World's agriculture, particularly, weed control, and the potential harm the new herbicide-based technologies may cause to mankind - if they are misused. Understanding the history of Weed Science, how we got to where we are – is important as we tackle future weed problems and associated issues.

Closing Remarks

I close my remarks by congratulating Dr. Nimal Chandrasena and Dr. A. N. Rao for making it possible to compile this Celebratory Volume. I thank them for improving my contribution. I also offer my best wishes to the APWSS and congratulating its current and past Executive Committees for keeping the Society alive, so that the membership can benefit from continuing the exchanges of Weed Science information, adding to the development of skills in the region for reducing the impact of weeds.

Memories and Reflections on Asian-Pacific Weed Science Society (APWSS) and Relationships with Bangladesh

Md. Hazrat Ali[52]

On this occasion of 50th Anniversary Celebrations of the Asian-Pacific Weed Science Society (APWSS), I am thankful for the Editors of this Celebratory Volume for inviting me to reflect upon the close relationship between the Bangladesh Weed Science Society and the APWSS and my own perspectives.

About APWSS

The Asian-Pacific countries cover a wide geographical area, with diverse landscapes, climates and cultures. Weeds are a major threat for sustainable crop production to feed the people and animals of the region and the whole world. Among pest damages to the crop yields, the damage caused by weeds exceeds that caused by any other agricultural pests. It is estimated that among the annual agricultural loss, weeds account for 45%, insects 30%, disease 20% and other pests 5% (Abouziena and Haggag, 2016).

The majority of countries in the Asian-Pacific region are highly populated, developing countries and emerging economies, perhaps with the exceptions of Australia, New Zealand, Japan and South Korea. In the developing countries, the importance of weed management on farmlands is generally under-estimated by the general public, many agricultural scientists, administrators and technologists.

The Asian-Pacific Weed Science Society (APWSS) was formed in 1967 at the first meeting, held at the Hawaiian Island of Kauai, Hawaii, USA, to "*facilitate the interchange of current weed control information and to promote research in Weed Science*". The Society provides a forum for the weed scientists to exchange their ideas with like-minded fellows of different countries of AP region. Since its inception, APWSS has maintained a liaison with other international societies, such as the International Weed Science Society (IWSS), Weed Science Society of America (WSSA), Weed Science Society of Bangladesh (WSSB), and a large number of other Weed Societies of the region.

APWSS continues to encourage weed scientists of the region to come together, share knowledge, develop networks and foster collaborations for solving common problems related to weeds and agriculture. The region has wealth of innovative technology and good practices along with an abundance of national human resources. APWSS has played a key role in the rapid institutionalization of weed management as a science in many universities and research institutes. Now APWSS is celebrating fifty years of its journey at the 26th APWSS 'Golden Jubilee Year' Conference at Kyoto, Japan during 19- 22 September 2017.

APWSS and Bangladesh

The economy of Bangladesh is primarily agrarian. About 79% of the Bangladesh population live in rural areas and are directly or indirectly engaged in a wide range of agricultural activities. The scope of modern agriculture in the country extends to the utilization of natural resources for the production,

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development, preservation, processing, marketing and extension of not only crops, but also other agricultural commodities, such as fish, meat, egg, and forest products. However, food crops undoubtedly constitute the largest and most important sector of Bangladesh. In cropping systems, weed control has a very important role, because of the negative impacts of weeds on growth of crops, on land values, human and animal health and the environment.

The humid climate of Bangladesh favours weed growth. Bangladesh also has an extremely fertile landscape (because of alluvial soils in river deltas) and warm, tropical climate, which offers favourable climatic conditions for the growth of invasive plants. Bangladesh's borders and ports are widely unprotected for invasion of exotic species of plants (Masum *et al.* 2013). However, in Bangladesh, there is not much attention in research on weeds and weed management, compared with other neighbouring countries.

Realizing the importance of adverse impacts of unmanaged weed infestations in the cropped and non-cropped lands, agricultural scientists in Bangladesh have been undertaking research and sharing their findings at various platforms. One such initiative was taken way back in 2008 when weed scientists of Bangladesh formed the Weed Science Society of Bangladesh (WSSB) to establish linkages and discuss what should be done in Weed Science; and I became the founder President of the Society.

Although geographically Bangladesh is situated within the Asian-Pacific region, prior to 2009, we had no information about APWSS. The avenue to properly join the APWSS family was opened when Dr. Steve Adkins (former President of APWSS) visited Bangladesh for the first time, in 2009.

Memories of 23rd APWSS Conference, Cairns, Australia in 2011

I was invited, for the first time from the Bangladesh, to participate as an oral paper presenter in 23rd APWSS Conference, which was held from 26–29 September 2011 at Cairns, Queensland, Australia. Others from Bangladesh - Dr. Md. Israil Hossain and Dr. Ilias Hossain also attended the Conference, representing Bangladesh. Dr. Israil gave poster presentation. Dr. Illias gave an oral presentation and was awarded with the Young Weed Scientist award at the 23rd APWSS Conference, which was an honour for the country. The 23rd APWSS Conference programs had welcome reception, plenary sessions, technical sessions, executive committee meeting, field trip and conference dinner, all of which I enjoyed. In the inaugural session, a keynote presentation was delivered in the presence of all the participants. Later, in plenary sessions, papers were presented by invited speakers. Technical sessions were divided into oral and poster presentations. For oral presentations, technical sessions were run concurrently, based on the research areas and topics. In technical sessions, time was allocated for discussions of results and findings.

It was indeed a great opportunity for all weed scientists to discuss different aspects within the field of Weed Science. The APWSS Executive Committee meeting was well organized and attended by all member countries. After open discussion at the meeting, the venues for 24th and 25th APWSS Conferences were announced as Indonesia in 2013 and India in 2015, respectively. I participated in the Executive Committee meeting, representing Bangladesh and was well supported by Dr. Steve Adkins, President, and Dr. Nimal Chandrasena, General Secretary, at that time.

I also participated in a field trip, which gave me an opportunity to see the countryside and different cropping systems of Australia. On the last day, I attended the Conference dinner, which allowed me the opportunity to meet other scientists, and discuss different issues, informally. Overall, the 23rd APWSS Conference gave me ample opportunity to exchange my scientific views with weed other scientists.

On my return, I prepared a collaborative research proposal on "An International collaboration on the biology, ecology and management of parthenium weed (*Parthenium hysterophorus* L.): an invasive alien weed threatening agricultural and natural ecosystems in Bangladesh". This was supported by Dr. Steve Adkins in Australia, who has collaborated with Bangladesh in this research. We recognized that international collaboration is essential for Bangladesh to share information on weed management practices and to establish an international centre for Weed Science research and farmer participatory training.

My Experiences with APWSS

From the year of my first participation in 23rd APWSS Conference, to date, APWSS has conducted two other APWSS Conferences in the region (i.e. Indonesia, in 2013; and India, in 2015). APWSS follows some strict rules and guidelines in selecting conference venues with different countries for each of the conference, and the decision is based on merit. At each conference, a new executive committee is formed by including members from different countries for the ensuing two years. At the completion of each conference activities, the Secretariat/Office of upcoming conference are transferred to the next venue hosting country. The information of APWSS Conferences are announced through the APWSS web page (http://apwss.org/apwss-contacts.htm), ahead of the conference date. Initially, dates of conference and abstract submission are declared. Names of Keynote speakers are also declared, ahead of time.

Weeds and weed management in Bangladesh

As in other Asian-Pacific countries, weeds (*agachha*) cause serious problem in Bangladesh. In the absence of specific or broad-scale weed surveys in Bangladesh, about 350 species have been incidentally recorded as important weeds of cultivated fields. The number of species in an area depends on the land use pattern and its ecological conditions. Of them, about one-third plants are monocotyledons (grasses and sedges) and the remaining plants are dicotyledons (broad-leaf weeds).

The most common weeds include species of the genera: *Echinochloa, Cyperus, Lindernia, Eragrostis, Digitaria, Panicum, Cynodon, Eleusine, Hygropylla, Euphorbia, Phyllanthus, Leucas, Scoparia, Croton, Celosia, Alternanthera, Heliotropium* and *Solanum*. Among aquatic weeds, *Eichhornia*, *Potamogeton*, *Pistia* and *Monochoria* spp. are the most common in deep water rice fields. Three species of ferns (*Marselia*, *Ceratopteris* and *Salvinia)* are also recorded as weeds of rain-fed rice. About 20% of the present Bangladesh weed flora are naturalized, exotic species. Among these are: *Parthenium hysterophorus*, *Chromolaena odorata*, *Mikania micrantha*, *Argemone maxicana, Alternanthera philoxeroides*, *Croton bonplandianum*, *Nicotiana plumbaginifolia*, *Lathyrus aphaca*, *Celosia argentea* and *Vicia angustifolia*.

Yield losses, due to weeds vary from 25-80%, and it also varies with types of crops. Reducing crop yield losses due to weeds is important to improve food security in the coming decades. Weed management strategies in Bangladesh have shifted from non-chemical weed management to the use of herbicides (Figure. 1), due to the increased availability and selective effectiveness of herbicides and shortage of labour. Estimates indicate that about 30% of rice farmers are losing about 500 kilograms per hectare of rice, due to poor weed control. Presently, farmer's net income can be increased by 100% with the use of herbicides (Anonymous, 2013). In recent years, as shown in Figure 1, there has been a considerable increase in herbicide use in Bangladesh.

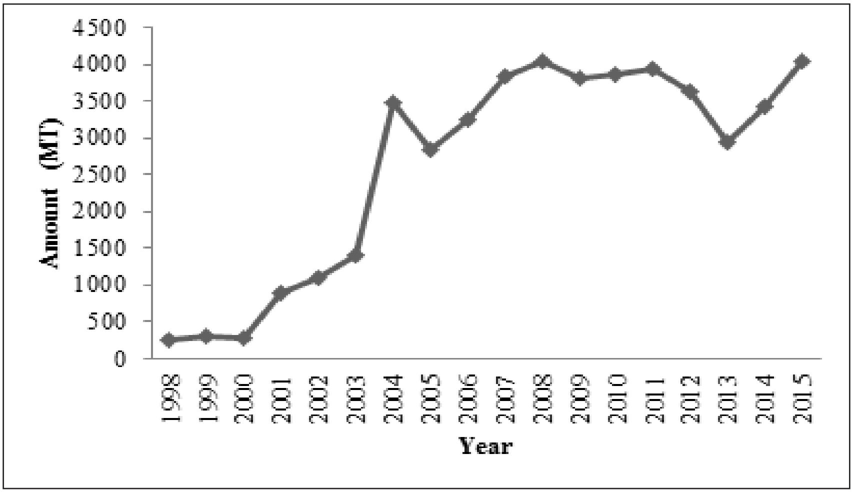

Figure 1. Trend of herbicide consumption in Bangladesh

(Source: Department of Agricultural Extension, Ministry of Agriculture, Bangladesh, 2017)

In Bangladesh, we are aware that the success of weed control depends on the selection of appropriate herbicides and their judicious application. The choice of herbicide depends on the level of weed infestations, the weed seed bank, types of weeds present in the fields and level of field management in previous seasons. Therefore, farmers need to consider all these aspects in selecting the appropriate herbicides. However, integrated weed management (IWM), incorporating all methods of weed control (manual, mechanical, biological and chemical control, and weed hygiene) is recognized as better than chemical weed control alone. When successfully implement, IWM is likely to reduce crop production costs, protect natural balances in cropping fields, conserve the environment, avoid the elimination of beneficial species, avoid injury to the main crops, encourage beneficial effects, and increase production.

Recent activities of the Weed Science Society of Bangladesh

The Weed Science Society of Bangladesh (WSSB) was established in August, 2008, as a result of efforts made by Dr. S.M. Rezaul Karim of Bangladesh Agricultural University. Since Weed research in Bangladesh is conducted indifferent research institutes, the need was felt for a platform of interaction among weed scientists to co-ordinate and strengthen interactions. Dr. Karim took this initiative, to unite all weed scientists as a common group, on 22 February, 2008 during a meeting at Bangladesh Agricultural Research Council (BARC), Dhaka. At the first executive committee, I was elected as President and Dr. Karim as General Secretary in an annual general meeting held at BARC on 8 November, 2008. Currently, the Weed Science Society of Bangladesh (WSSB) has 300 general members and 40 Life members.

The WSSB promotes research, education, and extension outreach activities related to weeds and invasive plants; provides science-based information to the public and policy makers; fosters awareness of weeds and invasive plants and their impacts on natural ecosystems; and facilitates professional development of its members. WSSB members are actively involved in addressing some of the most important issues facing our modern world. The overall aim of the Society is to enhance the agricultural productivity through economically feasible and environmentally friendly weed management strategies.

To achieve this aim, the Society was established with the following objectives:

- To provide with a forum for weed scientists to exchange their ideas with their fellow scientists;
- To maximize crop yields and feed a growing population as cropland is being rapidly lost to urbanization;
- To eliminate aquatic weeds that clog our waterways and impact on water quality;
- To control invasive weeds that pose a threat to biodiversity in our rangelands and wild areas;
- To develop integrated weed management techniques for both conventional and organic farming;
- To develop new and improved integrated weed management strategies in response to climate change;
- To suggest policies to the government for controlling noxious weeds;
- To maintain liaison with the international societies related to Weed Science;
- To boost agricultural production through coordinated efforts of the weed scientists by publishing research findings in Weed Science journals, bulletins, monographs, books, factsheets, etc.;
- To identify outstanding weed scientists in the country and recognize their contributions; and
- To recommend a high standard curriculum on Weed Science to the University Grant Commissions (UGC), Text Book Boards etc. for adoption in the agricultural universities, colleges and schools. These will have to be updated from time to time, as the discipline evolves.

The broader objectives of the WSSB are to promote the discovery of new, more environmentally acceptable weed management tools that not only control weeds effectively, but improve our understanding of weed ecology/biology and allow more sustainable management of the agro-ecosystem.

Since the establishment of the Society, it has arranged a general meeting, symposium and/or conference every year. At every annual conference, renowned weed scientists of the country are identified through nomination from different organizations, followed by selection. The selected scientists are given due honour with a token prize and a certificate. The best paper/poster presenters are also selected by a selection committee and are presented with awards at the conference. In addition, young and senior scientists who have made good contributions in Weed Science are rewarded with a cash prize and a certificate.

The best three post-graduate students engaged in Weed research are also rewarded, to encourage them in weed research. Bangladesh Journal of Weed Science (BJWS) is a half-yearly journal published in June and December on behalf of the Weed Science Society of Bangladesh (WSSB). The journal publishes original research papers, short communications and review articles in the field of Weed Science.

Major Challenges for Weed management in the APWSS Region

Research on weed management is generally not very well developed in many countries in the Asian-Pacific region, including Bangladesh. It is necessary, therefore, to give attention to expanding ecological studies on individual weeds (i.e. Studies of life cycle, weed seed viability, seed dormancy, growth habits and competitiveness with different crops and weeds). These should lead to the assessments of economic losses in different crops and costs of weed management, taking into account hazards to humans and animals and environment, due to weed infestations. The region will also benefit from studies on bio-diversity values, including medicinal values of weeds; the question here is – *can farmers benefit from these values?*

A major challenge for individual countries is to develop policies and regulations (i.e. Quarantine regulation, weed laws and acts), which would support to weed management. Biotechnology is changing agriculture in the region. Therefore, it is necessary for weed scientists to be involved in biotechnology to develop, acceptable Genetically-Modified (GM) crops; this should include developing highly competitive crop varieties having C_4 photosynthetic ability, and/or allelopathic (weed suppressing) capacity.

Further development of Sustainable Weed Management Systems (incorporating biological, cultural, allelochemical, molecular techniques, etc.) integrated with herbicides, is required. Addressing concerns of the public weed scientists should also undertake on-going studies on herbicide use and assess the degradation and residual effects of herbicides in soil and water, so that the environment risks herbicides can be mitigated.

It is also necessary to keep an eye out for species that can become future problems, through surveillance of different countries. Risk assessments are required to assess the potential of entry of new invasive weeds to the region, so that preventative action can be taken.

Recommendations/Suggestions

I would like to make the following recommendations to the APWSS to address the above-mentioned challenges:

- International collaboration should be strengthened for the control of invasive weeds, promoting integrated weed management. The present paradigm in Weed Science should be restructured to meet the challenges of the 21st Century for sufficient food production without environment hazards. This should extend Weed Science to accommodate biotechnology: herbicide resistant, transgenic biotech crop varieties; development of allelopathic crop varieties and allelochemical-herbicides and/or bio-herbicides/agents;
- Herbicide manufacturing companies should be encouraged to produce new herbicides and develop technologies to combat resistant weeds. Our region suffers from inadequate training of weed scientists, professionals, workers, and farmers in the safe use of herbicides and Companies should assist training.
- Awareness building program should be taken up by the Government for different stakeholders on Integrated Weed Management (IWM). Scientists should develop weed management policies and regulations, including plant quarantine, covering areas of internal legal aspects, education, research, extension, economic, social, ecological and environmental consequences.
- To tackle the complex weed problems, weed research must involve, systems analysis, weed population and community analysis, weed traits and eco-physiology, molecular biology and genetics, assessment of shifts in weed communities, herbicide resistance and issues related to transgenic plants and the, environment, as well as potential benefits of weeds. Such areas are poorly developed in several countries of the region.
- Agricultural advisory personnel are inadequately trained in many developing countries. They need to be trained further to enable them to co-ordinate extension efforts to educate farmers on judicious and safe use of herbicides, as well as integration of herbicides with other weed management practices. I also feel that Weed Science related syllabi in the different universities should be more updated with global context. Perhaps, the region can also benefit from a Asian-Pacific Region Weed Control Board, which can help national or international weed related problems.

Conclusions

There are 490 million people still suffering chronic hunger in the Asian-Pacific region, which is home to almost 62% of the World's undernourished people. Feeding this ever growing, large volume of the world's population is not possible without the intervention of sustainable weed management for increased and sustainable crop production, minimize crop losses, save human and animal health, while reducing environmental hazards. Ineffective cultural and mechanical weed management results in significant yield losses throughout the world. Effective weed management consists of many factors that vary from crop to crop and year to year depending upon different cropping system. The present paradigm in Weed Science should be restructured to meet the challenges of the 21st century for sufficient food production without environment hazards.

The scope of Weed Science should be expanded to accommodate biotechnology in Weed Science, which should include the use of genetically modified (GM) crops, allelopathic (weed-suppressing) crops and highly competitive crops, and to utilize all the useful genes for bio-production through re-evaluation of the virtues of weeds and weed relatives. Risk assessments and monitoring of herbicide residues are needed in agro-ecosystems, to reduce negative impacts. International collaboration is needed to share information on weed management practices and to establish international centers for Weed Inventories and farmer participatory training. In this context, APWSS is playing a vital role in the Asian-Pacific region. However, there appears to be an on-going need for more collaborative research and activities, through the Society, so that different countries can develop Weed Science aspects further.

Acknowledgements

I wish to thank Dr. Shaikh Tanveer Hossain (Asian productivity Organization, Tokyo, Japan) and Sheikh Muhammad Masum (Sher-e-Bangla Agricultural University, Dhaka, Bangladesh) for providing information for the article. The Editors of this Celebratory Volume are also thanked for improving my manuscript.

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APWSS: Much Headway to make

N. T. Yaduraju[53]

It is my utmost pleasure to give my impressions on the historical occasion of the Golden Jubilee 50th Year of existence of the Asian-Pacific Weed Science Society (APWSS). My own association with APWSS has not been a long one, unlike that of many of my friends and peers. However, it was very intense during the period 2011-13, firstly, as President-Elect and then, as President, during 2013-15.

As a hard-core and full time Weed Scientist, since my college days in the late 1970s, I had been aware of the APWSS. There was an opportunity for me to attend the 8th APWSS Conference held in India, during 22-29 November, 1981 at Bangalore; however, I could not attend, as I headed to the United Kingdom on a Commonwealth Scholarship in October, 1981 to pursue my Ph.D. program at the then Weed research Organization (WRO), at Oxford. My attempts to participate in the succeeding Conferences were also unsuccessful, primarily due to lack of financial support. Although I could not attend the 19th APWSS Conference at Manila, due to the same reason, my paper was published in the proceedings (Yaduraju and Kathiresan, 2003).

My first participation was at the 20th APWSS Conference, held at Ho Chi Minh City, Vietnam, in 2005. My friend and colleague, Dr. Duong Van Chin, the President of APWSS at that time, who happened to do his Ph.D. at the Indian Agricultural Research Institute New Delhi, where I was then employed, was kind enough to provide some financial assistance. I presented a plenary paper and co-chaired one of the sessions. In my plenary paper, I spoke on "History and development of 2, 4-D" (Yaduraju and Prasad Babu, 2005), which I would strongly recommend for students and budding weed scientists to read.

With generous support from Dr. Steve Adkins, the President of APWSS during 2009-2011, I was able to attend the 23rd APWSS conference at Sebel Cairns, Australia in 2013 and again present a plenary paper (Yaduraju, 2011). I presented a paper "Weed management perspectives for India in the changing agriculture scenario in the country", highlighting weed management options for the small-holder farmers in India. In a third plenary address, at the 24th APWSS, at Bandung, Indonesia, I spoke on "Implications of weeds and weed management on food security and safety in the Asia-Pacific region" (Yaduraju and Rao, 2013), which was well received by the participants.

It is at Cairns, Australia, in 2011, that the idea of India hosting the 25th APWSS 'Silver Jubilee' Conference was first seeded. Many APWSS leaders felt that it was long overdue for India to host the conference. In fact, as there were no strong bidders for the 2013 conference, there was pressure on India to host the 2013 Conference in India. However, as the Indian Society of Weed Science, at that time, was in some internal turmoil, we suggested a delay, until matters stabilized. Indeed, it did stabilize within a short period, and India made a successful bid during the 2013 Conference at Bandung, Indonesia for hosting the 25th APWSS Conference.

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The 2013 Bandung Conference was a memorable occasion, as India was successful in our bid and got the opportunity to host the next APWSS event after a long gap of 34 years. Personally, it was indeed a proud moment for me. I still cherish the time when I frantically waved the APWSS flag after receiving it from a Past-President - Dr Steve Adkins. It was a happy coincidence that we had the largest contingent from India, present at Bandung, to cheer me, and to celebrate the occasion. The rest is part of APWSS's proud, recent history.

We worked very hard over the next two years and were able to host one of the most memorable conferences ever in the history of APWSS. As we realized that it was a 'Silver Jubilee' (25th Conference), we rightly decided to observe the occasion in a befitting way. To celebrate the occasion, we planned a special publication, and consulting widely with other senior weed scientists, the title and contents of the publication were finalized.

I am happy that Dr. V. S. Rao - one of the respected weed scientists and author of many books on Weed Science - agreed to head the Editorial Team, which also included myself, Dr. Nimal Chandrasena, Dr. Gul Hassan and Dr. A. R. Sharma. I am very proud that the editorial effort produced the publication, entitled "*Weed Science in the Asian-Pacific Region*" (Rao *et al*., 2015). This Volume is a unique publication, because it is probably the first effort of its kind, compiling information on the status of Weed Science in 19 countries of the Asian-Pacific region. This 389-page book with 19 Chapters, contributed by 47 weed scientists from 19 Countries, is a mine of information on the status of Weed Science in the region. The 25th Silver Jubilee Conference did have few other distinctions as well, which are listed below:

- The Conference attracted the largest number of delegates with 690 registered participants, including 107 from overseas and 46 from industries. There were 11 plenary lectures, 16 lead presentations and 106 oral presentations, besides 627 poster presentations.
- Probably for the first time, five satellite symposia on emerging topics were organized. They were on: (1) Weed management in Conservation Agriculture; (2) The Weedy Rice Challenge in Asia Issues and Options for Management; (3) Herbicide Resistance: Current Status and Future Challenges globally; (4) Biological Control – Progress and Future prospects in Asia-Pacific region; and (5) Utilization of Weeds as Bio-resources. These were well organized by the symposia coordinators and were well attended and well received.
- The 'Silver Jubilee' occasion by way of the 25th APWSS Conferences was observed with the launching of the special publication "Weed Science in the Asian-Pacific Region". It was indeed heartening to listen to some of the veterans of APWSS (Dr. Anis Rahman, Dr. Nimal Chandrasena, Dr. Steve Adkins and Dr. A. N. Rao, to name a few), who spoke on the occasion, and took the audience down the memory lane.
- Another unique feature of the Conference was a pre-conference workshop on ARM Statistical Software, attended by 25 participants. It was conducted by Dr. Steven Gylling of Gylling Data Management and was facilitated by Dr. Samunder Singh of the International Weed Science Society (IWSS).

Overall, organizing the 25th APWSS Conference gave me great personal satisfaction and this occasion can be called as one of the high points of my career. I received guidance, help and support provided by many friends and peers in the APWSS and ISWS. I am thankful to all of them. I particularly grateful to Dr. Nimal Chandrasena who took a keen interest in all our activities. His active role in identifying

Plenary Speakers and facilitating their presentations was particularly praise-worthy. In organizing the Conference, I also acknowledge with gratitude the help and support received from Dr. A. R. Sharma, the Director, DWR, Jabalpur, and the General Secretary of ISWS at that time; and Dr. A. N, Rao, the APWSS General Secretary.

APWSS: Way forward

Over the years, the discipline of Weed Science has grown exponentially in almost all countries. However, there is a huge disparity in awareness and understanding of the importance of weeds and the technology adopted for management of weeds. There is also the dearth of competent human resources, particularly in less developed countries, to deal with the ever-increasing problem of weeds. Weeds and their management is likely to be even more significant, particularly under a changing global climate and its impact son water and other resources.

The APWSS has been playing a vital role in networking weed scientists of the region and outside in sharing information and knowledge. However, it lacks much-needed vibrancy and dynamism Apart from the mandatory biennial conferences and publication of the newsletter, there is hardly any activity worth mentioning, with the exception of Parthenium network, which is spearheaded by Dr. Steve Adkins. The popularity of the network illustrates how stewardship and perseverance will bear fruits.

During my Presidency, some degree of consultation on forming different Focus Groups in major areas took place. Despite Dr. Dierdre Lemerle's efforts, nothing worthwhile has come out of it. The problem is not in identifying the champions in steering the Focus Groups, but the overall lack of interest and enthusiasm within our own Weed Science community. Communications even with some of the country representatives often evokes little response. I am not sure why this happens, in this technological era. Is it to do with the diversity in languages spoken? Or, other social and cultural factors? Is it because, our region's communication methods have not quite caught up with basic e-mail contact etiquette (i.e. rapid responses)? However, I feel that this communication glitch can be overcome if APWSS could position itself as an organization worthy to be part of.

Besides the determined efforts of a few, dedicated individuals, APWSS, as an organization, needs money. Unfortunately, the Society is not on a good financial footing. The mandatory 10% of the registration fee collected during the APWSS Conferences is not always paid back by the host country. I am proud to say that India contributed 10% of the registration fee collected at the Hyderabad Conference to the APWSS treasury. I suggest that this be a mandatory rule, rather than an exception, in all future conferences. Enrolling of new members is far from satisfactory. During my tenure as President, we introduced different membership fees for individuals, regional societies and corporates, but we could not make much headway. This is unlikely to succeed, unless the affiliated, national Weed Science Societies and Country Representatives take the lead.

There is also a strong feeling that we should revisit the constitution. This view was supported at the Annual General Meeting at the Hyderabad Conference. I am aware that this is currently being looked at. A permanent place as headquarters of the Society, open elections for the office bearers and launching of an official journal of the Society are some of the things that need to be critically looked at. In my opinion, launching an official journal publication of the APWSS in the not too distant future should receive greatest attention. This will be a very effective academic activity, which is likely to infuse interest among members, besides generating income.

I am doubtful that it would be possible to 'adopt' the Japanese Society's well-established journal *Weed Biology and Management* as APWSS's official journal. At the 26th Conference, which is happening in Japan, I urge the current APWSS leadership to flag this issue for discussion and reach a possible decision. I hope that some of these suggestions are considered by the current APWSS leadership. I hope my expectation of a strong and vibrant APWSS will come true soon.

As a Past-President, I offer my very best wishes on the Fifty years of celebration of the APWSS.

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Asian-Pacific Weed Science Society (APWSS) and the Malaysian Plant Protection Society (MAPPS)

Abdul Shukor Juraimi[54]

As the President-Elect of the Asian-Pacific Weed Science Society, representing Malaysia, I am honoured to provide this congratulatory message for the 50th Anniversary Celebratory Volume. I also take the opportunity to share some thoughts on the historical role Malaysia has played in the APWSS, as one of its earliest members.

Historical Background of MAPPS

The history of the foundation of The Malaysian Plant Protection Society (MAPPS) dates back in 1971. However, MAPPS was officially established as a Society in 1976 with the primary objectives of promoting and advancing the science and practice of plant protection in Malaysia.

Since its formation, MAPPS has been active in fulfilling these objectives and has contributed significantly to the transfer of integrated pest management (IPM) technologies through numerous activities. MAPPS has currently over 600 members, of whom 112 are life members. Several members are from overseas countries, namely from Australia, Canada, Egypt, France, India, Indonesia, Japan, Nigeria, Pakistan, Philippines, Singapore, Taiwan, Thailand, United Kingdom and United States of America. More than >50% of MAPPS members are currently actively engaged in various aspects of plant protection research and implementation, including Weed Science. The majority of the members belong to private agrochemical companies, followed closely by government research organizations, academic institutions and plantation industry. MAPPS, being a professional society, continues to participate in the development and implementation of IPM programs in Malaysia. The Society's involvement in the drafting of the national IPM Policy by virtue of its membership in the Steering Committee bears testimony of its recognition by governmental authorities as an important organization which could contribute towards plant protection in the country.

Current office bearers - 37th MAPPS Council 2016/2018

The current office bearers of MAPPS include: Dr. Hafidzi Mohd Noor (President); Dr. Abdul Shukor Juraimi (President-Elect); Dr. Siti Izera Ismail (Honorary Secretary); Dr. Sumaiyah Abdullah (Assistant Honorary Secretary); and Dr. Norida Mazlan (Honorary Treasurer). Council members are: Dr. Nur Azura Adam; Dr. Latiffah Zakaria; Dr. Muhammad Saiful Ahmad Hamdani; Mr. Meor Badli Shah Ahmad Rafie; Mr. Yahutazi Bin Chik; Mr. Erwan Shah Bin Shari. More details are available from the Website: http://www.mapps.org.my.

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Experience of MAPPS in Organizing APWSS Conferences

The Malaysian Plant Protection Society (MAPPS) was first involved, as the co-organizer of the 3rd Asian-Pacific Weed Science Conference (APWSS), held during June 7-12, 1971 at the Federal Hotel, Kuala Lumpur, Malaysia. About 200 delegates, from 20 countries, participated in 3rd APWSS Conference.

At the 14th APWSS Conference held at Brisbane, Australia, in 1993, MAPPS initiated and won its bid to again host this premier regional conference on Weed Science, i.e. the 16th APWSS.As a result, Malaysia hosted the 16th APWSS Conference in 1997 with leadership from MAPSS, together with Malaysian Agricultural Research and Development Institute (MARDI) and the Universiti Malaya (UM) as key organizers of the Conference. The first announcement flyers were circulated and distributed in July 1995 at the 15th APWSS Conference in Tsukuba, Japan, and the final Conference announcement was made in January 1997. "*Integrated Weed Management Towards Sustainable Agriculture*" was our chosen theme.

The 16th APWSS Conference was a significant event for Malaysia, as that was the second time, Malaysia got an opportunity to host the biennial APWSS Conference. The five-day conference was attended by 326 participants of which, around 200 were foreign delegates from the Asian-Pacific region, as well as the other continents - Europe and Africa. The 16th APWSS Conference in Malaysia was officially declared open by Mr. Datuk Dr. Michael Leo Toyad, the Deputy Minister of Foreign Affairs, Malaysia, at the Ballroom of the Kuala Lumpur Hilton on September 8, 1997. Following the 45 minute ceremony, the Deputy Minister was taken on a tour of various exhibits that were put on show by about 10 different companies/organizations at the venue. He also viewed the poster session in the adjoining hall where around 52 posters were put up by participants. This was followed by a press conference and tea reception, prior to the commencement of the actual Conference proceedings.

The Conference, with its selected theme "*Integrated Weed Management Towards Sustainable Agriculture*", focused its attention on: biology and ecology of weeds; progress in herbicide research and development; advances in biochemistry, physiology and performance of herbicides; herbicide resistance and management; weed management in food production systems, plantations, pastures and forests and in small-holder agriculture; biological control, crop-weed interactions and allelopathy and legislation and environment management.

The conference proceedings were initiated with a Keynote address on "*Sustainable Weed Management - fact or fallacy*" by Dr. W. M. Blacklow of The University of Western Australia (UWA), Perth, Australia. In addition, there were four other invited speakers, who delivered their respective plenary papers for each day's technical sessions. All in all, there were 8 sessions, seven being concurrent, with a total of 95 oral papers and around 52 poster papers presented. The oral papers presented were compiled as a 406-paged proceedings and the abstracts of the posters were compiled separately, as a supplementary publication to the conference proceedings.

A specially-prepared field trip to commercial and public-funded research stations and an oil palm plantation was also included as part of the conference program. A special field guide consisting off ourfield trips was made available to every participants as 12-page booklet. The competitions on herbicides and weed identifications were at the CCM Bioscience Research Centre, in Melaka, and the Novartis Experimental Station in Rembau; and prizes were distributed to winners.

A booth showcasing various weed exhibits and a chance for participants to take part in the various competitions were additional attractions during the Conference. Trade exhibitions were organized by the conference sponsors. A two-day (13-14 September, 1997) satellite meeting was arranged by the MOC under the chairmanship of Mr. Ho Nai Kin in the rice granary areas in Kedah/Penang for interested participants to get acquainted in rice industry developments in Malaysia. This post-conference seminar was attended by more than 100 overseas and local participants. A Conference Dinner was held on the 9th of September. A 20-minute Video Show, showcasing Malaysia's varied tourist spots were shown at the start. During the course of the dinner, various events ably conducted by Dr. Rohani Ibrahim were performed among which was group-singing by invited countries, lucky draws, etc. In addition to the official dinner, two other dinners were hosted by Kumiai Chemical Industries of Japan on Monday, September 8, and Cyanamid Singapore, on Thursday, September 11, 1997. At the closing ceremony on Friday 12 September 1997, various awards were presented. Monsanto gave awards to three each of best non-industry oral papers and poster papers. MAPPS presented two awards: one for the best oral paper and the other for the best poster paper. Novartis gave prizes to winners of competitions that were held during the field trip at its station. Mementos in the form of pewter plaques were given to four APWSS officials, viz: President, Hon. Secretary, Treasurer and Newsletter Editor, who had served the Society from 1993 to 1995. Following these presentations, the conference was declared closed by the outgoing APWSS President - Dr. Ahmad Anwar Ismail.

Engagements and Contributions of MAPPS at APWSS Conferences

The Malaysian Plant Protection Society has always been continuously supporting and participating in the APWSS conferences and meetings. At every APWSS Conference, MAPPS members have actively participated, either as Conference Office-bearer, or as participants, presenting research findings as oral presentations and poster exhibition. MAPPS's association with APWSSC began as early as 1971, when Malaysia became organizer in the 3rd APWSS conference in Kuala Lumpur. In 1979, MAPPS had officially embarked as an affiliate society of APWSS in the 7thAPWSS Conference in Sydney, Australia. Since then, MAPPS has proactively and continuously associated with the APWSS Conferences. Dr. Ismail Sahid and Dr. Baki Bakar received invitations as plenary speakersin2003 at the 19th APWSS Conference in Manila, Philippines; and in 2005 at the 20th APWSS Conference in Ho Chi Minh City, Vietnam, respectively. In 2015, at 25th APWSS conference in Hyderabad, India, six MAPPS delegates attended the conference and presented their research findings in various Weed Science disciplines.

It was an unforgettable moment when MAPPS also received an honorable responsibility to organize in 2019, the 27th APWSS Conference, which will be held in the beautiful and culturally rich Kuching City, in Sarawak, Malaysia. As the current MAPPS President-Elect (formerly the President), I was appointed as the Vice President of APWSS, as Malaysia was chosen to carry forward the noble task of being the next APWSS Conference host following the 2017 26th APWSS Conference in Kyoto, Japan. The MAPPS's involvement is not only limited to APWSS Conferences, meetings, and workshops, but also extended to various contributions in scientific writing. MAPPS's most distinguished and long serving member, retired Dr. Baki Bakar has been continuously sharing his expertise and experience in APWSS publications as the country's representative. In the Silver Jubilee 25th APWSS Conference in 2015 at Hyderabad, Dr. Baki shared his thoughtful wisdom in Weed Science disciplines from Malaysian perspectives in the book entitled, *"Weed Science in the Asian-Pacific Region*" edited by a number of senior APWSS Members.

Today, MAPPS is proud to represent Malaysia in the APWSS and world widely, promoting sustainable crop protection through good practices in all aspects related to weeds, pests, and disease management.

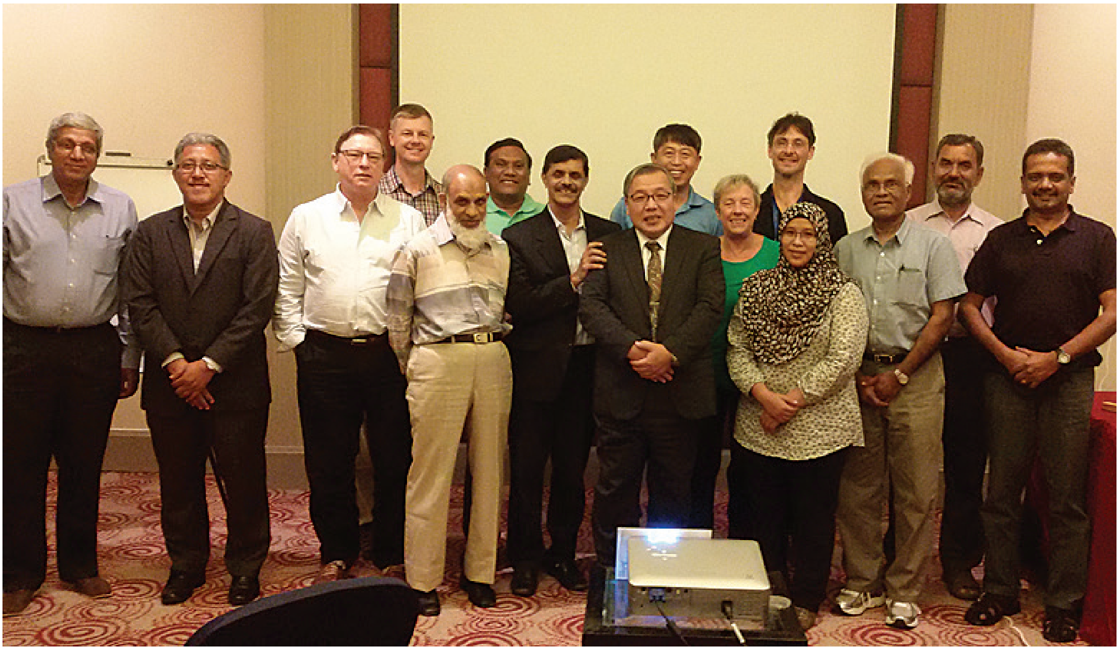

Photo: 1. MAPPS was represented by Abdul Shukor Juraimi (*second from left*) and Nur Azura (*fourth from right*) at the APWSS Executive Committee Meeting (with Invitees) at which MAPPS won the bid to organize the27th APWSS Conference in 2019.

Others in photo, from *left to right*: A. N. Rao (India, General Secretary); Steve Adkins (Australia); Michael Widerrick (Australia); Anis Rahman (New Zealand); Nimal Chandrasena (Australia); N. T. Yaduraju (India, President); Y. Fujii (Japan); Do-Soon Kim (Korea); Deidre Lemerle (Australia); Michael Renton (Australia, Treasurer); V. S. Rao (USA); A. R. Sharma (India); Buddhi Marambe (Sri Lanka)

Forthcoming 27th APWSS Conference in 2019

I close my contribution with an Invitation! The Malaysian Plant Protection Society is proud to organize the upcoming 27th Asian-Pacific Weed Science Society Conference in 2019 under the theme "***Weed Science for Sustainable Agriculture and Environment***". As previous APWSS Conferences, this conference will also focus on developments in Weed Science and discuss particular challenges faced by researchers, practitioners and consumers on problems related to weed invasion, environmental impact and sustainable management. This 27th Conference is also expected to inspire new research and establish new relationships and international collaborations, and meet the next generation of weed scientists.

The 27th APWSS Conference is to be held in Kuching, Sarawak, Malaysia. Kuching is a vibrant destination that offers a wide range of high class accommodation, facilities, shopping plazas, museums and impressive nooks to explore in Kuching, not to mention the nightlife and bustling Kuching Waterfront. Delegates may treat themselves to an enriching experience of exploring the dazzling rainforest and enjoy the rich and colourful Sarawakian culture! MAPPS will continue to work closely and actively with the APWSS as a gathering platform for weed scientists in the Asian-Pacific region, as well as from all over the world.

We look forward to welcoming you in Kuching, Sarawak in September 2019!

Reflections of Asian-Pacific Weed Science Society and Contributions

Surajit Kumar De Datta[55]

It is with great pleasure that I send this brief note, reflecting on some important past memories and reflections on the Asian-Pacific Weed Science Society, as it celebrates 50 years of existence.

It has been awhile since I attended some of the APWSS Conferences. Hence, my memories are somewhat distant. However, those which I have attended, helped to organize, and remember, have been full of good memories. I remember that after the 1st APWSS Conference at Hawaii in 1967, the 2nd APWSS Conference was held in the Philippines, during 16-20 June 1969. The Conference was hosted and organized by the Weed Science Society of the Philippines. It was held at the International Rice Research Institute (IRRI) and the Organizing Committee was composed of Dr. Beatriz Mercado and myself, and other IRRI and University of Philippines at Los Banos (UPLB) scientists and faculty, led by Dr. Marcos Vega, the first President of the APWSS.

With my IRRI co-workers, we presented results of our studies on granular herbicides newly introduced to Asia for control of weeds in transplanted rice, which was a significant development at that time. At later conferences, we presented new technologies for weed control, also in broadcast-seeded rice, as well as new post-emergence herbicides for the control of grass weeds in rice, something that was not possible before post-emergence grass herbicides were developed. In my scientific career at IRRI, which lasted 27 years, I attended as many APWSS Conferences as possible. Even after moving to a role in International Affairs at Virginia Tech. at Blacksburgh, USA, during the next 20 years, I attended several Conferences. I have also delivered several keynote addresses and plenary lectures at the APWSS Conferences, on invitation (De Datta, 1989, 1995, 2003; De Datta and Flinn, 1985), in addition to presenting several scientific papers with my colleagues and students.

With these presentations, I believe, I have had the opportunity to share the results of our research, particularly on weed management in rice. I am proud to state that this research and interactions, played an important role in my own career and helped me gain insights and valuable experience, including friendships and collaborations with other scientists throughout the Asian-Pacific region. Among my best memories are the three Best Paper Awards, which we won three times with my co-scientists and students. The first was in 1987 with A.M. Baltazar and M.A. Llagas (Baltazar *et al*., 1987); the second was in 1989 with K. Ampong-Nyarko (Ampong-Nyarko and De Datta, 1989); and the third was in 2001 with UPLB and PhilRice co-scientists (Casimero *et al*., 2001).

In the tropical South and Southeast Asia, the primary emphasis for Pest Management in the 1960s was on insect and disease control. Weed Science were not in vogue and weeds were robbing precious harvests from food grains, fruits and vegetables. At that time, commencing in 1967, the APWSS provided a forum for scientific interactions and knowledge sharing. Weed Science, gradually gained distinct credibility as

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an important scientific issue in pest management, and not a side-lined issue of Pest Management in the Asian-Pacific region, largely due to the efforts and co-ordination achieved by APWSS and its affiliated Weed Societies of different countries. The regularly-held APWSS Conferences gave the scientists also greater visibility and increased resources for weed science research in the region. I vividly remember the unique characteristics of APWSS Conferences, which were attended by scientists from the Asian-Pacific region. The Conferences were colourful events, because of the multi-cultural attendees and activities. The countries included tropical South and Southeast Asia, which were among the most food insecure regions of the world.

Most of the APWSS meetings were also well attended by scientists, science administrators and representatives from educational institutions, such as the UPLB and other Universities in the region. This also gave me opportunities to meet my old friends, make new friends, and periodically meet with colleagues in Weed Science from Japan, Korea, India, Indonesia, Malaysia, Thailand, Taiwan, Philippines, Hawaii and mainland USA, Australia, and New Zealand. Participants from China were limited at that time. Looking back, these positive exchanges with like-minded weed scientists are etched in my memory.

I wish the participants of the future APWSS Conferences great success in their pursuit of their careers. I also hope that the next generation of weed scientists will continue the legacy of the APWSS founding fathers and with regard to applying effective and appropriate approaches and methods to manage weeds without harming the environment. That is a legacy we can pass on to future members for the next 50 years!

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Some reflections, experiences and views on the future of APWSS

Bhagirath Singh Chauhan[56]

It is with great pleasure that I send this congratulatory message to the Asian-Pacific Weed Science Society in its celebrations of 50 years of existence. I have been closely associated with the APWSS since 2013, and am privileged to be the current APWSS Newsletter Editor.

I am presently the leader of the Weeds Research team at Queensland Alliance for Agriculture and Food Innovation (QAAFI), based at the University of Queensland, Gatton, Australia. Before joining the University of Queensland, I worked at the International Rice Research Institute (IRRI), Philippines. Despite working in Asia, I did not get a chance of attending APWSS conferences until 2013. While working at IRRI, for the first time, I got an opportunity of attending the APWSS Conference held in Indonesia in 2013. My Ph.D. students accompanied me to attend that Conference, at which I met several weed scientists and Weed researchers. It was an interesting event, and it increased my interest in research activities in the Asian-Pacific region. In 2014, I moved to the University of Queensland, which has provided me with greater opportunities for interacting with researchers and students of different Asian countries as my current work is not limited to rice alone.

Later, in 2015, I attended the 25th APWSS Conference held at Hyderabad, India, which was attended by more than 700 people from all over the world. There were several interesting symposia and presentations made in sessions with different themes at the conference that were very well organised by the Local Organising Committee. I made several presentations, including a lead presentation and a lecture to students and young researchers on "Publishing in International Journals", at the Hyderabad Conference. More than 50 participants attended this lecture, and it gave me another opportunity for interacting with students. I also organiseda special symposium on "Weedy Rice".

At this 25th APWSS Conference at Hyderabad, APWSS presented me a Young Scientist Award for my contributions in Weed Science. This was a great honour, and I felt privileged at the occasion. I was also given the responsibility of becoming the next Newsletter Editor for the APWSS Newsletter. This too was a special honour. I am expected to publish two APWSS newsletters per year. We publish new research activities and results. The Society is very crucial to me, and I will keep working hard to contribute to its betterment.

Views and Suggestions

I feel that the APWSS has a great future. However, based on my experiences in working across the region, I do have a few suggestions, which may help to raise the standard of the Society at the global level. These suggestions are made for consideration by the Society membership, as well as broader Weed research community, working in the Asian-Pacific region.

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- Larger number of students and young weed scientists should be encouraged to attend the APWSS Conferences. APWSS is already providing travel grants to some students, but I feel that the number can be increased. Industry should be encouraged to come forward from their respective countries and fund the attendance of some students and young researchers directly.
- I feel that there should be a journal published by the APWSS. At the moment, *Weed Biology and Management* (WBM) is the only international Weed Science journal published in Asia (Japan). It is not free, so most researchers working in developing countries cannot publish their articles in this journal. The APWSS should approach Springer or Elsevier for a possible new journal on 'Weed Science Research', which should publish research papers of researchers from developing countries, free of cost.
- The APWSS should award researchers and students from the Asian-Pacific regions, the best paper awards in different categories; for example, ecology, molecular biology, management, etc. There should be an independent committee for the selection of these awards.
- During the Conference, there should always be a session on "weed problems and possible opportunities in different Asian-Pacific countries" and related information should be updated at every Conference organised by the APWSS.
- During the oral paper presentations at the conference, the time allotted to each speaker should be strictly followed, so that there is enough time for interactive discussions. This would enable participants to attend presentations of their interest in concurrent sessions.
- In the Asian-Pacific region, there should be more interaction of Weed researchers with multinational companies. Visits to the headquarters of the Chemical Industry/companies should be encouraged. Such exposure-visits and interactions will benefit researchers from the region. On a national level, Weed Science Societies of each country, affiliated to APWSS, must be encouraged to have a closer liaison with Industry, so that linkages can be renewed or established.
- At the Universities in the region, there is a need to involve more basic research work (e.g., weed ecology) on different weed aspects. Most of the work in some countries focuses only on herbicide evaluation. Climate change is now a reality; however, very limited research work is currently in progress on the impact of climate change on weeds.
- There should be course work on molecular biology. Advance knowledge about the mechanisms, spread and stability of herbicide-resistant weeds may help to manage herbicide-resistant weeds more effectively.

I thank the Editors of this Celebratory Volume for the opportunity to provide some insights and suggestions to make APWSS a better and more effective community.

Reflections on Linkages with the Asian-Pacific Weed Science Society (APWSS) – the Sri Lankan Context

Buddhi Marambe[57]

Introduction

Reflecting on our own experiences encourages insight and complex learning, and fosters our own growth. We need to act upon the information, synthesis and evaluations done, applying what we have learned to settings beyond the original situations. In this context, to analytically look back on the five decades of the efforts made by the Asian-Pacific Weed Science Society (APWSS), the professional body comprising of scientists, academia, private/corporate sector and weed management practitioners in the Asian-Pacific Region, and its evolution, with a view to have a progressive visualization for its future, is highly opportune. Being a Past-President of the APWSS (2005-2007), I consider it a privilege to be a partner of this exercise, first to recall on how weed scientists in Sri Lanka formed into an official body and from there on, the formal involvement with the APWSS.

Similar to many other developing countries, weed scientists have been a rare breed in Sri Lanka. However, despite low numbers of qualified personnel, the importance of weeds and their negative impacts on sustaining a food secure nation have never been overlooked by stakeholders, ranging from policy makers to practitioners in Sri Lanka. Moreover, it is also important to note that the weed scientists in Sri Lanka did not form into an official body until 1990, with no initiative reportedly being brought forward by any interested parties, up to that time. Although there may have been discussions mooted in different forums, this vacuum resulted in the absence of any Sri Lankan Weed Scientist formally in the APWSS Executive Committee, until 1999.

History of Weed Science Society of Sri Lanka

The Weed Science Society of Sri Lanka (WSSSL) was established in April 1990 with the support from Department of Agriculture, Faculties of Agriculture in the Universities and the agro-chemical industry in the country, with Dr. Mervyn Sikurajapathi (Department of Agriculture) and Dr. Nimal Chandrasena (University of Colombo) as the first President and General Secretary, respectively. The WSSSL had its first conference in 1992 and published the Volume 1 of the journal "*Tropical Weeds*" and also undertook several activities, including a training workshop, mainly targeting participants from the Chemical Industry. The Second National Weed Science Conference in Sri Lanka was held in 1995.

There were no national level Weed Science Conferences or Symposiums held in Sri Lanka, since 1995, and the journal "*Tropical Weeds*" also had a natural death since then, due to the absence of adequate number of high quality research papers. Other conferences and symposia, organized in general subjects within agricultural and biological sciences in Sri Lanka regularly gave the opportunity for the low numbers

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of weed scientists in the country to publish elsewhere, thus leading to the culmination of publishing the journal "Tropical Weeds". The departure of some key members from Sri Lanka probably contributed to the slow progress in those early years.

Making efforts to reach the farming community to support their struggle on weed control, the WSSSL organized "1000-Farmer Training Programs on Integrated Weed Management in Rice" targeting rice-growing farmers in six districts in Sri Lanka, namely, Anuradhapura and Polonnaruwa (North Central Province), Hambantota and Galle (Southern province), Kurunegala (North Western Province) and Ampara (Eastern Province). This activity received support from the staff and students of the Faculty of Agriculture, University of Peradeniya, the Government Department of Agriculture, Provincial Departments of Agriculture and the private sector. Approximately 6000 farmers were trained during the period, which was a significant achievement of the WSSSL. The WSSSL, at its Executive Committee meetings held in January 1999, decided to be an active partner of the APWSS, which was much belated and anticipated. As a consequence, as the Country Representative for Sri Lanka, I attended the 17th APWSS Conference held in Thailand 1999.

Weed Science Society of Sri Lanka co-opted to the National Plant Protection Association (since 2000)

The year 2000 brought in many changes to the WSSSL with the intervention from the Sri Lanka Council for Agricultural Research Policy (SLCARP), which is the apex policy-making arm of the Ministry of Agriculture, Sri Lanka, to establish the National Plant Protection Association of Sri Lanka (NPPASL). The objective was to bring in all sectors involved in Plant Protection research, training, development and extension into one forum to form a strong national level body. In responding to the request of SLCARP, the WSSSL Executive Committee and the general membership agreed to join the NPPASL, which was considered important at the national level for providing state involvement in Plant Protection Activities.

The Executive Committee and membership decided not to dissolve the existing Weed Science Society, but to conduct its activities through the NPPASL. As a result of that decision, a special segment of Weed Science was formed under the NPPASL, and I, along with Dr. Lakshman Amarasinghe (Department of Agriculture), took on the responsibilities to coordinate the Weed Science-related activities. The membership of the WSSSL actively took part in various workshops, seminars and other forms of capacity building programs organized by the NPPASL and the association has been representing Sri Lanka in the APWSS, since 2001. In 2001, several National Committees were set up to provide advice to the Government of Sri Lanka, and the National Plant Protection Committee (NPPC) was established in late 2001. The NPPC served as the apex body for plant protection in policy making, while the NPPASL continued to represent the larger membership, including the Weed Science group (*note*: the WSSSL has not been dissolved to-date). Subsequently, I became the Chairman of the National Plant Protection Committee (NPPC) for the period 2006-2012, which is another milestone achievement for weed scientists in Sri Lanka, and to the field of Weed Science, as a whole.

Building relationship with APWSS

Weed scientists in Sri Lanka have been attending the APWSS since early stages. Records indicate that several weed scientists have attended APWSS Conferences in the late-1970s and early-to-mid 1980s. However, no official records are available to show that the Weed Science Society of Sri Lanka (WSSSL) has formally taken part in APWSS-related activities, at least since 1990 (the year of establishment of

WSSSL). The first record of official participation came in 1999, when two members (myself and Ms. Kosala Jayawardena of the Department of Agriculture) were officially nominated by the Executive Committee of the WSSSL to be the Country Representatives to the 19th APWSS Conference held in Thailand. Since then, Sri Lanka has been represented in the APWSS as an affiliated Society with a Country Representative in the Executive Committee. With the establishment of the NAPPSL, Ms. Anuruddhika Abeysekera became the Country Representative in 2001-2003, while I functioned in the same role from 2003-2005.

An important achievement by the Sri Lankan weed scientists in 2003 was the establishing of strong relationships with the APWSS within a very short time span. The 19th APWSS Conference held in Philippines accepted the bid forwarded by Sri Lanka to host the 21st APWSS Conference in 2007. This enabled me, as the Sri Lankan Country Representative, to be elevated to the post of Vice-President (President-elect) of the APWSS for the period 2003-2005. Sri Lanka then became the host country for the 21st APWSS in 2007, and I took over the Presidency of APWSS for the period 2005-2007 at the 20th APWSS held in Vietnam, with Ms. Anuruddhika Abeysekera functioned as the General Secretary of APWSS in that period.

21st APWSS in Sri Lanka

The period in which the 21st APWSS was held in Sri Lanka (2007) was hectic, as the country was still suffering from a more than 30-year long terrorist war, covering the Northern and a part of Eastern Provinces of the Country. The impact of terrorism was felt in other parts of the country as well, with the business capital Colombo as the focus, and many leading weed scientists from the Asian-Pacific regions showing their reluctance to attend the Conference. Despite the obstacles, the 21st APWSS Conference was held in Sri Lanka successfully from 2-6 October 2007 in Colombo, Sri Lanka. The Conference was jointly organized by the APWSS, NPPC of the SLCARP, NAPPSL and the Agribusiness Centre (AbC) of the Faculty of Agriculture at University of Peradeniya, Sri Lanka. The Conference received very high political patronage as well where both the Hon. Minister of Agriculture and Agrarian Development (currently, His Excellency, the President of Sri Lanka) Mr. Maithreepala Sirisena, and the Hon. State Minister of Agriculture Mr. Hemakumara Nanayakkara gracing the occasion. No adverse incident took place in Sri Lanka during the period when the 21st APWSS was being held, in Colombo, which was a great relief to all participants.

Milestones achieved at the 21st APWSS Conference held in Sri Lanka

The Conference achieved several milestones apart from participation of 189 members representing 19 countries participating as I reflect below.

- The total number of papers presented was 134, inclusive of 107 oral presentations, and 27 poster presentations. There were 27 Technical Sessions; Oral presentations were made in three parallel sessions. The proceedings of the Conference were issued in two volumes; namely, the Technical Papers (Volume 1) and the Plenary Sessions (Volume 2). The Conference Proceedings were edited by an Editorial Board and the publication was sponsored by Messrs CIC (Pvt.) Ltd. and University of Peradeniya, Sri Lanka.
- For the first time in APWSS's history, Excel Crop Care Ltd. of India sponsored the Young Scientist Awards. Dr. Abhijit Bose, of Excel Crop Care (now with Opex Holdings, Colombo) made this a reality. This was of special significance as Monsanto, USA, which had been the usual sponsor of the

award since 1983 had ceased to sponsor the award at the 20th Conference in 2005, and thereafter. The awards, named as "*Excel Young Scientist Awards*", were given to young and deserving scientists, who were selected based on the quality of the papers presented at the Conference. The "*Excel Young Scientist Award* "continued at the 22nd APWSS held in Pakistan (2010) and at the 23rd APWSS, held at Cairns, Australia (2011).

- The special 40th anniversary commemorative volume of the APWSS, edited by Dr. Aurora Baltazar, was released at the inaugural session of the 21st APWSS Conference and copies were presented to all participants. A special plaque commemorating 40 years of the APWSS was presented to all participants.
- With the generous support from the private sector organizations, the Conference Organizers were able to organize social activities every evening of the days of the conference.

22nd APWSS Conference onwards

Sri Lanka, unfortunately could not take part in the 22nd APWSS held in Pakistan in 2010, due to the unfavourable security situation that prevailed during the time, which led to the postponement of the Conference by several months. However, Sri Lankan weed scientists, representing the NAPPPS and NCCP continued to participate in the 23rd, 24th and 25th APWSS Conferences, held in Australia, Indonesia and India, respectively. The participation at the 23rd Conference in Australia by two Sri Lanka scientists (myself and Dr. Rohan Rajapakse) was sponsored by AusAID, as a result of a request made by the APWSS Organizing Committee.

Apart from the 21st APWSS Conference held in Sri Lanka, participation of the highest number of Weed scientists and industry personnel from Sri Lanka was recorded at the 25th Conference held at Hyderabad in India. At the 25th Conference, a Sri Lankan participant from the Department of Crop Science of the Faculty of Agriculture, University of Peradeniya (Ms. L. V. Y. Weerarathne) was able to win the Best Poster Award. This was the first time a Sri Lankan won such an award, at an APWSS Conference, since 1997. I record this as an encouragement to all young scientists from Sri Lanka, who intends to attend the Conference in the future.

Future of the APWSS and the APWSS Conferences

The APWSS celebrates its 50th year in 2017, since the inception of its first bi-annual conference in 1967, held at Hawaii, USA. The Conference has been the main bi-annual forum for the weed scientists in the region to update their knowledge on latest developments in the field of Weed Science and also for the all-important aspect of networking. The APWSS, its past and present Executive Committees and the general membership should be congratulated for keeping the momentum in this regard.

The introduction of life membership, which was initiated at the 25th APWSS in India, needs further promotion clearly stating the benefits especially in terms capacity building. It is also a necessity that all participating countries be advised at every bi-annual conference to enlist the respective weed/plant protection societies/association with the APWSS to make the society grow in strength further. Initiatives to support at least one member from the national societies would facilitate this process further making the APWSS the common scientific voice in all Asian-Pacific countries in Weed Science related activities.

With a low number of hard-core weed scientists in Sri Lanka, many agronomists who are carrying out research on weed management have been participating at the APWSS Conference over the years, at least in some numbers, since 1997, representing the country. This is encouraging on the one hand. However, on the other hand, representation of the weed scientists and those involved in Weed Science related activities in Sri Lanka at national and international level development programs have been "low-key".

In many instances, scientific justifications have been undermined in countries like Sri Lanka in the wake of politically strong ideas, put forward by the pseudo-scientists. The recent ban imposed on glyphosate and other policy level directives in Sri Lanka has resulted in serious negative effects on weed control in both annual and perennial crops, crop yields, and ultimately, profits from farming, and food security. This is a classic example of science being ignored for other considerations. Weed scientists in Sri Lanka are also to be blamed, although low in number, for not making a strong representation and impact in this regard, with the assistance of professional bodies, such as APWSS. There is a dire need to strengthen bonds between APWSS and national partner societies/association, and fighting not only against weeds, but also pseudo-scientific ideas and viewpoints promoted for political purposes.

Proper training on Weed Science is an important aspect in the progression of Weed Science, and hence, continuing professional development programs have become imperative for furtherance of the science and its practical implications. The APWSS has initiated several technical workshops in the past. However, it seems that the events are not continuing at sufficient frequency, or that information regarding such events are not reaching the relevant societies and associations at national level. An effective mechanism should be adopted in this regard to ensure that continuing professional development programs in weed science be supported by APWSS with financial support from international and national donor agencies.

Recently, as announced at the 25th APWSS Conference in India, a commitment was made by Sri Lanka to develop training modules in Invasive Alien Species and their management. Such training modules have been prepared through international consultations and with the financial assistance from the Global Environment Facility (GEF) and the modules are now ready to be offered for international participants. This development has already being communicated to the APWSS. If such programs are offered, APWSS can review the modules first and also be the main partnering organization. Currently, participants from Sri Lanka are being trained using these training modules.

The APWSS should establish regional working groups (e.g. SAARC), to promote research and development on current and emerging issues such as climate change, invasive alien plants, herbicide-resistant weeds, and weedy rice. This can strengthen networking and multi- and inter-disciplinary activities leading to organize more specializing symposia during the bi-annual conference to attract leading scientists in these special subjects of national, regional and global importance, and increase participation in the APWSS conference.

Sri Lanka has already established a National Invasive Species Specialist Group and National Experts Committee on Climate Change Adaptation, both under the Ministry of Environment with the approval of the Cabinet of Ministers, which can act as the national arms to support such initiatives on regional working group.

Memories of Asian-Pacific Weed Science Society Conferences

Chanya Maneechote[58]

It gives me a great deal of pleasure to send this brief note, on invitation by the Editors of this Celebratory Volume, reflecting on my own past memories of the Asian-Pacific Weed Science Society (APWSS), as it celebrates 50 years of existence. Representing Thailand, which is one of the earliest members of the APWSS and as the current President of the Thailand Weed Science Society, it is an honour for me to send this message.

Early encounters with APWSS

The rotation of host countries of APWSS Conferences, since the Society began its journey in 1967, has given an opportunity for weed scientists from the Asian-Pacific region to visit different countries; interact with different cultures and learn how people deal with weeds in their agricultural endeavours. In my own association with APWSS, this aspect is one of the most satisfying experiences that I can reflect upon. I first attended the 10th APWSS Conference, held at Chiang Mai, Thailand, during 24-30 November, 1985. Since then, I have attended 10other APWSS Conferences, and would like to recall some of my wonderful memories, as below.

I was a Master's Degree student in Weed Science at Kasetsart University, when I first attended the 10th APWSS Conference (1985) in Chiang Mai, Thailand. There, I had a chance to meet several famous weed scientists at that time, whom had I known from their papers in journals. I was hesitant to talk to them, as I was a student and my English was not good enough. However, I began to develop my network with the foreign students, who had similar difficulties. I was fascinated by several talks on modes of action of new herbicides. By that time, I have no idea what they were talking about. Later, I realized that the 1980s indeed was a golden age of herbicides in our region, which contributed to dramatic increases in weed control efficacy and increased crop yields.

The 14th APWSS Conference (1993) in Brisbane, Australia, when I was in second year of my Ph.D. program at the University of Adelaide. My supervisors (Drs. Steve Powles, Joe Holtum and Christopher Preston) decided to send all Ph.D. students to the Conference to orally present papers. On the day of my presentation, I vividly remember being scared of talking in front of nearly 500 people in the room. Moreover, I had to answers two aggressive questions from the audiences. It was the most scaring moment in my academic life and I did not know how I passed that moment.

Surprisingly, at the end of the Conference, my research paper on "Acetyl CoA carboxylase is a mechanism of resistance to diclofop-methyl in *Avena sterilis*" was announced as the best paper award. Unfortunately, I did not attend the closing ceremony because I had to accompany Thailand researchers from my department for sight-seeing tour. After the award was delivered to my University and my photograph appeared in Adelaide News. It served as an incentive for me to continue to workhard in Weed Science.

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A large group of Thai weed scientists (from both government and private sectors), including me, led by Dr. RungsitSuwannaketnikom attended the 16th APWSS Conference (1997) in Kula Lumpur, Malaysia. At that conference, Thailand was given the honour of hosting the 17th APWSS Conference.

Participating at APWSS Events

On behalf of the Weed Science Society of Thailand, I served as the Master of Ceremony at the opening and closing ceremonies of the 17thAPWSS Conference (1999) held in Bangkok, Thailand. I enjoyed this role immensely and also presented two papers.

I also enjoyed the opportunity to participate and present papers at the 19th APWSS Conference (2003) in the Philippines; 20th APWSS Conference (2005) in Vietnam; 21st APWSS Conference (2007) in Sri Lanka; 23rd APWSS Conference (2011) in Australia; and the 24th APWSS Conference (2013) in Indonesia.

Some of my papers have received awards for the "Best Paper" presented at the 14th APWSS Conference (Maneechote *et al*., 1993) in Brisbane, Australia; and the "Best Poster" (Maneechote *et al*., 2003) at the 19th APWSS Conference (2003) in Manila, Philippines. These are extremely important mementos of my own Weed Science career and achievements.

I have also participated and presented a paper at the one day workshop on "*Echinochloa* Control in Rice", organized by Dr. K. U. Kim (Kim and Labrada, 2003), prior to the 18th APWSS Conference (2001) in Beijing, China. Subsequently, I also attended the one day workshop on 'weedy rice' organized by Dr. Ricardo Labrada, FAO during the 20th APWSS Conference (2005) at Ho Chi Min City in Vietnam. I also took part in an attempt to formulate a regional project of weedy rice management; however, the project did not materialize.

At the Vietnam Conference, a second one day workshop was also held - on "Management of Sedges Weeds in Rice" (Kim and Labrada, 2006), which I attended. By participating I expanded my understanding of these serious weed problems in our region.

During the field visit days of APWSS Conferences, I had the opportunity to visit the following, which were highly educational experiences:

- The Great Wall of China, the Ming Tomb and one farming community near Beijing (18th APWSS Conference 2001, China);
- The gene bank at IRRI, herbicide efficacy field trials at the Bayer Station and a small village making a cloth from pineapple leaves in Los Banos (19th APWSS Conference, 2003, Philippines);
- Mekong River and the fruit crops plantations in Vietnam; There was a heavy rain when we were in a small boat, and we enjoyed singing the songs of different language until the rain stopped (20th APWSS Conference, 2005, Ho Chi Minh City, Vietnam);
- The Royal Botanical Garden and the famous Temple of the Tooth (Buddha) at Peradeniya, Sri Lanka (21st APWSS Conference, 2007, Colombo, Sri Lanka).
- Queensland Plant Quarantine Service; examined the research on biological control of *Salvinia molesta*, weed spread prevention project of local government, banana and sugarcane plantations in Brisbane (23rd APWSS Conference, 2011, Cairns, Australia).

To me, APWSS Conferences are full of joy, mixed with knowledge in Weed Science and friendships among people from different countries. When we interact and exchange ideas and opinions, we do not feel that we come from different countries and backgrounds at all. Indeed, friendships are the greatest benefit for me in attending APWSS Conferences. Just like for me, the Conferences offer opportunities for young scientists to build research network and increase awareness of new weed problems in the Asian-Pacific region.

Please allow me to endorse that APWSS Conferences are amongst the greatest conferences in Weed Science. Hence, I am looking forward to attending again in this 50th Anniversary Celebratory Year 2017 in Kyoto, Japan.

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Asian-Pacific Weed Science Society (APWSS) and the Weed Science Society of Pakistan (WSSP)

Gul Hassan[59] and Khan Bahadar Marwat[60]

It is with great pleasure that we send this congratulatory message to the APWSS in its celebrations of 50 years of existence. We believe that the development of Weed Science as a discipline in Pakistan was influenced significantly by the association with the Asian-Pacific region, through the APWSS. This is why we appreciate APWSS and reciprocate by maintaining strong linkages with the Society. We hope that in future years weed scientists from Pakistan would strengthen this relationship further and benefit from it.

Genesis of the Weed Science Discipline in Pakistan

Research

West Punjab (now part of Pakistan) and the East Punjab (now part of India) are very fertile areas producing cotton, rice, wheat, sugarcane and an array of other crops. Hence, the then British Rule in India, in order to cater to the needs of the farming community in East and West Punjab, commissioned Punjab Agriculture College and Research Institute Lyallpur (presently Faisal Abad, Pakistan) during the dawn of last century i.e. 1909 (Hassan and Marwat, 2015), which through the evolutionary process has emerged now as the world class Agricultural University, viz. University of Agriculture, Faisal Abad. The foundation of agriculture, and Weed Science, dates back to the commissioning of Punjab Agriculture College and Research Institute Lyallpur, presently the University of Agriculture and Ayub Agriculture Research Institute, Faisal Abad, Pakistan.

The Punjab Agriculture Research Institute was also upgraded to become the Ayub Agricultural Research Institute in 1960, which now has hundreds of researchers in its staff in every discipline, including weed scientists, working under the umbrella of the Plant Physiology Section. Dr. Asghar Jalis headed this section during 1970's and 80's and made a major impact in introducing herbicides as a tool in crop husbandry.

Likewise, in the North-western Pakistan, a Research Farm at Tarnab, near Peshawar, was established during 1908, almost at the same time when the Punjab Agriculture College was created in 1909 at Lyallpur. It has also been upgraded over time to a multi-disciplinary institute. The Agricultural Research Institute (ARI) Tarnab contributed significantly to the promotion of agriculture in Khyber Pakhunkhwa Province in the areas of horticulture, plant breeding and variety development, crop protection and agronomy. Research on weeds was initiated at this institute during 1972, with one of us (Gul Hassan) being a pioneering member of the Staff. However, this Weed Science Program could not flourish like the sister disciplines of

[59] Professor of Agriculture/Weed Science, Shaheed Benazir Bhutto University, Sheringal Dir Upper, Pakistan.; General Secretary, APWSS (2008-2009); General Secretary, Weed Science Society of Pakistan (WSSP) (1996 – to date).

[60] Professor of Agriculture/Weed Science; Vice-chancellor, Shaheed Benazir Bhutto, University, Sheringal Dir Upper Pakistan; President, APWSS (2008-2009); President, Weed Science Society of Pakistan (WSSP) (1996 – to date); Winner of Tamgha-i-Imtiaz, Quaid-i-Azam Gold Medal, President's Gold Medal and Fellow Pakistan Academy of Sciences, Islamabad, Pakistan.

Plant Pathology and Entomology and is still under staffed. Other Agriculture Research Institutes (ARIs) in Tando Jam, and ARI, Sariab Quetta, are located in Sindh and Balochistan provinces, respectively, and have been serving the farming communities of those areas for decades. At the federal level, a very strong agricultural research network exists in the form of Pakistan Agricultural Research Council (PARC), which was established in 1979. It has a research institutes at the federal level and research stations in all provinces. Established in 1984, the National Agriculture Research Center (NARC), based at Islamabad, is Pakistan's biggest research establishment, with agricultural focused research on high-value agriculture, productivity improvement; sustainable resource use and environmental protection (http://www.parc.gov.pk/index.php/en/2013-04-11-06-13-50/narc-islamabad).

A real boost to Weed Science in Pakistan resulted with the assistance from USAID under PL 480 with initiatives from Drs. Peter Hobbs and Naeem Hashmi, Consultant from the International Maize and Wheat Improvement Center (CIMMYT) and Coordinator of the Wheat Program at NARC, respectively. Under this US assistance, a Training Program for weed scientists and agronomists from all over Pakistan was organized during 1982. Mr. Myron Shenk and the late- Dr. Larry C. Burrill from the International Plant Protection Center (IPPC), Oregon State University, Corvallis, USA were the Training Resource people.

The Program was coordinated by Mr. Mohammad Munir, the then Scientific Officer in Wheat Program, who later received Ph.D. degree in Weed Science from the Oregon State University, USA in 1988. Apart from training of weed scientists at NARC, USAID also sponsored the National Coordinated Program on weeds throughout Pakistan. By the same trainers and the coordinator, a similar training, but jointly sponsored by the USAID and the Barani (Rainfed) Areas Research and Development Program of Pakistan Agricultural Research Council, Islamabad was organized during 1983. The major emphasis of these training programs was on identifying major weeds in major crops of Pakistan and their management through herbicides.

Another milestone at NARC was the organizing of the Pak-Indo-US Workshop during March, 1987 (Shad, 1987) which also was financed through USAID, in which weed scientists from across the two nations attended the collaborative approach. This coordinated effort paved the way for strengthening Weed Science in Pakistan.

Education

The Punjab Agriculture College, established during the first decade of 20th century, not only promoted agriculture in the West Punjab (Pakistan), but also in East Punjab (India) by educating their youth in agriculture. The leading educational institution in Weed Science in Pakistan is the University of Agriculture, Peshawar (UAP), which is the only University in the country offering B.S., M.S. and Ph.D. degrees in Weed Science. 15 Ph.D. degrees, apart from several B.S. and M.S. degrees in Weed Science were awarded by it so far.

The creation of a separate Weed Science Department was achieved with a US assistance program for the uplifting of the University of Agriculture Peshawar. This was through the Transformation and Integration of Provincial Agriculture Network (TIPAN) program. TIPAN's design Team recommended in 1983 to include Weed Science into the galaxy of Academic Programs at UAP. On completion of Ph.D. degrees in Weed Science (K. B. Marwat, in 1988, from the University of Illinois, Urbana, Champaign, USA; and Gul Hassan, from the Oregon State University, Corvallis, Oregon, USA, in 1992), we strived to establish a separate Weed Science Department at UAP for some years. We were successful in the year 2000, and the Department is a viable entity now.

The University of Agriculture, Faisal Abad (UAF) is the leading agriculture university in the country. Weed Science work at this university is undertaken at the Department of Agronomy. The work on allelopathy in weed management was commenced by Dr. Zahid Ata Cheema, which his group is continueing successfully, after his retirement. The earlier work on weeds was initiated at UAF by the late- Dr. Saeed Ahmad.

NARC, at Islamabad is also a degree awarding institution offering degrees in several fields of Agriculture, including Weed Science. Their joint efforts have led to promoting Weed Science, as a discipline, in Pakistan. Presently, several other institutions viz. Sindh Agriculture University, Tandojam, Sindh, PMAS University of Arid Agriculture Rawalpindi, Lasbela University of Agriculture, Water and Marine Sciences, Lasbela, Balochistan, and the recently established Muhammad Nawaz Sharif University of Agriculture, Multan, are worth mentioning with regard to awarding Weed Science-related degrees. Very recently, the Faculty of Agriculture, Gomal University Dera Ismail Khan has been upgraded as Mufti Mehmood Agricultural University, Dera Ismail Khan. Although all of the above named institutions offer courses in Weed Science, the subject is offered as a separate discipline only at UAP.

The Weed Science Society of Pakistan - Establishment and Present Status

Coordinated by Dr. Rashid Ahmad Shad, the then Director Weed Science Research Institute, NARC, Islamabad, a group of scientists gathered at NARC in 1987, probably at the time of Pak-Indo-US Weed Science Workshop during March, 1987, to form professional society with the name Pakistan Weed Science Society (PWSS) [Hassan and Marwat, 2015]. Present among others at that time were Dr. Mir Hatam, UAP. Dr. Sadruudin Siddiqui, Mrs. Shahida Khalid and Dr. Tahira Z. Mehmood from NARC, Islamabad, Dr. Saeed Ahamd and Mr. Zahid Ata Cheema from UAF, Dr. Asghar Jalis and Mr. Karim Bakhsh from Ayub Agricultural Research Institute, Faisalabad, Mr. Ghulam Sarwar Khan, ARI, Tarnab, Peshawar and Mr. Abdul Sattar Larik from ARI, Tando Jam, Sindh.

All attendees supported the idea of establishing the Pakistan Weed Science Society (PWSS) and elected Dr. Rashid Ahmad Shad, as its first President. The meeting nominated National and Regional Coordinators, which included Dr, Rashid Ahmad Shahid as National Coordinator, Dr. Munir A. Nayyer, Mr. Muhammad Umar Makhdoom, Dr. Khan Bahadar Marwat and Mr. Muhammad Anis as the Regional Coordinators of Punjab, Sindh, Khyber Pakhtunkhwa and Balochistan provinces, respectively. The late-Professor Saeed Ahmad was successor of Dr. Rashid Ahmad Shahd as the President PWSS.

The Society commenced publishing the Pakistan Journal of Weed Science Research in1988. However, due to some constraints, the publishing of the journal stopped after 1994. After the creation of Weed Science Department at UAP in 2000, the head office of PWSS was shifted to Peshawar along with its journal. The name of the Society was also changed to be the Weed Science Society of Pakistan (WSSP). The Society was then registered under the Societies Act of Khyber Pakhtunkhwa Province, Pakistan. The journal was re-commenced and website of the Society viz. www.wssp.org.pk/ was launched. A discrepancy in ISSN of the journal was also resolved. The journal was recognized from the Higher Education Commission of Pakistan in the category “Y”. At the time of this revival, the journal was published bi-annually in 2002, while now it is published quarterly, in both on-line and print modes (Hassan and Marwat, 2015).

Organizing conferences has been a regular feature of the WSSP. To date, the Society has organized 13 conferences (both national and international) at important locations in the country. The highest achievement of the WSSP is winning the bid and holding the 22nd APWSS Conference in Lahore 2010.

The WSSP journal also had the honour of publishing the full proceedings of two APWSS Conferences – those of the 22nd APWSS Conference, held in2010 at Lahore Pakistan; and the 23rd APWSS Conference, held in 2011, at Cairns, Australia.

Linkage of Weed Science in Pakistan with APWSS

The association of Weed Science personnel in Pakistan with the APWSS is not very old. However, since attending the 19th APWSS Conference in Manila Philippines, on March 16-21, 2003, there has been representation at all Conferences. One of us (K. B. Marwat) alone attended the Manila Conference. The failure to attend the Indian Conference was due to the inability to obtain visas in time for a large contingent from Pakistan, who were interested in attending. However, Drs. Zahid Ata Cheema managed to obtain visas and attended the conference in Hyderabad, India. Although we could not personally attend the Hyderabad Conference, we contributed a chapter for inclusion in the APWSS Silver Jubilee Book and one of us (Gul Hassan)is among its editorial team.

The largest Pakistan group to attend an APWSS Conference was at Ho Chi Min City, Vietnam, at the 20th APWSS Conference in 2005. At this Conference, we won the bid to hold the 22nd APWSS Conference in Pakistan. In the aforesaid Conference, we met Dr. Steve Adkins of the University of Queensland, Brisbane, Australia. Acquaintance with him resulted in a Joint International Linkage Project on "Biology, Physiology and Ecology of *Parthenium hysterophorus* L." sponsored from the Higher Education Commission, Islamabad, Pakistan at a cost of Rs.12.24 million (Rs.100 equals 1 US $ approximately).

Under this linkage, four Pakistan students worked with him at the University of Queensland for their Ph.D. degrees, and three other students worked with him for their split Ph.D. Programs. Two Exchange visits between Australia and Pakistan were also undertaken. One of us (Gul Hassan) was also sponsored to attend 23rd APWSS Conference at Cairns, Australia, in 2011. Thus, Dr. Steve Adkins has played an appreciable role in strengthening Weed Science in Pakistan.

22nd APWSS Conference in Lahore

The 22nd APWSS Conference was held at Government College University, Lahore on 8-12 March 2010 under the Theme "Judicious weed management – road to sustainability". The Conference was organized by two of us, serving as APWSS General Secretary (Gul Hassan) and APWSS President (K. B. Marwat), respectively, while serving in those capacities, since 2007. The International Weed Science Society extended financial support to the Conference; and Dr. Abhijit Bose of Excel, India, provided the financial support for the Young Weed Scientist Awards. The other major donors for the APWSS Conference was the Higher Education Commission, Islamabad, and Jaffer Brothers Pakistan Ltd., which were highly appreciated. Three sponsorships were offered by APWSS for delegates from abroad to attend the Conference. Dr. Robert L. Zimdahl, Colorado State University, USA and Dr. Jamal R. Qasem, University of Amman, Jordan attended. However, the third invitee - Dr. Haji Baki Bakar of the University of Malaya, Malaysia, was not able to attend, due to visa problems.

Figure 1. Delegates at the 22nd APWSS Conference, Government College University, Lahore March 2010

Front Row only: Second, third and fourth from left are: Steve Adkins (Australia); Robert Zimdahl (USA) and Gul Hassan; sixth and seventh from left – Soekisman Tjitrosemito (Indonesia) and Khan Bahadar Marwat. First on the right is S. M. Rezaul Karim (Bangladesh)

A total of 140 Abstracts were submitted for oral presentations and about 75% of these were presented at the Conference. The security situation in Pakistan was not very conducive at that time, which delayed holding the Conference towards the latter part of 2009. Despite this, delegates from nine countries participated in the Conference (USA, Australia, India, Indonesia, Iraq, Bangladesh, Jordan, Sudan and Pakistan).

The Excel Young Scientist Awards went to:

- Dr. Irfan Rashid (University of Kashmir, Jammu & Kashmir, India) for his paper on: ‘Plasticity facilitates *Anthemis cotula* to invade diverse habitats’;
- Mr. Ikramullah Khan (University of Queensland, Australia) for his paper on –‘Weed seed spread by vehicles: A Study from Southeast Queensland, Australia’; and
- Mr. Rahamdad Khan (University of Agriculture, Peshawar, Pakistan) forth paper entitled: ‘Proximate analysis and mineral composition of major winter weeds found in Northwest Pakistan’.

The Conference hosted the welcome reception, lunches and dinners on all conference days and the closing Gala dinner at the Government College University, Lahore, Pakistan. Since Lahore was a historic city, on the last day of the Conference (12th March 2010), which was to be devoted to the field excursion, delegates visited the Indo-Pakistan border at Wagha on the late afternoon of 11th.

During all weekdays, there is a special Flag-raising ceremony in the morning and evening at the border. All participants enjoyed the very sentimental scene from the people of the two countries. Some of the participants rated it as one of the most enjoyable visits of their life.

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Commemorating 50 Years (1967 - 2017)

50th Anniversary Celebratory Volume Asian-Pacific Weed Science Society

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Dr. Adusumilli Narayan Rao is a Consultant Scientist at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Hyderabad, India. Dr. A. N. Rao has led various research projects on weed management in various crops and is an expert in disseminating integrated crop-weed management methods for obtaining optimal and sustainable crop productivity. Dr. Rao worked as an Agronomist (Weed Science) at the International Rice Research Institute (IRRI), in the Philippines and Egypt. His Ph.D. thesis was: "Eco-physiological responses of crops and weeds against herbicides and their residues". He did postdoctoral studies at ICRISAT (1978 to 1980) and IRRI (1985 to 1988). He has authored more than 150 research publications, including book chapters. He is a Fellow of the Indian Society of Weed Science (ISWS) and is also a recipient of the ISWS Gold Medal in recognition of contributions to Weed Science. Dr. Rao began his association with APWSS in 1981, when APWSS conference was held in India. The current APWSS Logo was designed by Dr. Rao, while at IRRI, which won him the Ciba-Geigy Best Logo award in 1985. He functions as an Associate Editor of the Indian Journal of Weed Science and others. He became APWSS General Secretary at the 25th APWSS Conference at Hyderabad, and is the current incumbent in that role.

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Indian Society of Weed Science (ISWS)
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