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"The Role of Weed Science in Supporting Food Security by 2020"

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IMPLICATIONS OF WEEDS AND WEED MANAGEMENT ON FOOD SECURITY AND SAFETY IN THE ASIA-PACIFIC REGION

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ABSTRACT The food price crisis of 2007 and 2008 caused widespread food shortages and food and nutrition insecurity the world over. Home to the largest number of poor and undernourished people in the world, the Asia and Pacific region (APR) was at the epicenter of the crisis and was hit extremely hard. Although food prices have eased since then, recent studies indicate that food prices will remain high and volatile in the future. Reducing the existing large crops yield gaps is one of the appropriate approaches to meet the growing regional food security demands. Crop yield gap reduction is possible by optimizing crop productivity through identification and alleviation of major impediments such as weeds, which are more adapted to wide range of environments. Weeds continue to cause yield losses ranging from 10 to 60% depending on the crop and associated environment. Appropriate weed management has the potential to ensure food security by enhancing productivity and increasing profitability of farmers by cutting costs. Judicious selection, integration and proper application of herbicides will guarantee consumers the safety of foods they consume. However, impact of globalization, climate change, genetically modified crops and other recent trends, also have an impact on weeds and weed management. Severe labour scarcity, shortage of water for agriculture, emphasis on organic and conservation agriculture, are redefining the way we address weed problem. The solutions adopted by the developed countries may not suit the vast majority of the countries in the APR. It is time to evolve APR's own strategies and approaches. Besides these technological challenges, APR countries have to grapple with the problems of different sort such as the ignorance of vast majority of farmers about the weed problem, the inadequate capacity of the extension personnel and the insensitive administrators and policy makers. The weed scientists in APR countries have a daunting job at their hands to deal with this multitude of problems. Optimal weed management solutions, to meet the food security and safety needs, could be evolved from networking and collaboration with weed scientists from the developed countries in the region as well as from the other parts of the world.

Keywords: Yield gap, integrated weed management, food security, climate change, Asia Pacific region.

INTRODUCTION

Agriculture in the Asia and Pacific region (APR), accounts for 11% of the gross domestic product (GDP) and over 50% of total employment. In 2009, there were 1 billion hungry people in the world, an increase of about 100 million over the previous year. In the APR alone, the number of under nourished people increased by over 60 million in 2009 to 642 million. Food security has once again become a major issue for the world as the world population increased from 3.5 billion in 1970 to 8 billion in 2011 and is expected to reach 9 billion by 2050. Increasing population is putting pressure both on available cultivatable land and on yields required. In 2011, 925 million people suffered from chronic malnutrition, on average 16% of the population in the developing world, and this can be expected to worsen if there is no increase in world food production. With approximately 3.5 billion people, APR is

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home for 58% of the world's population. Reducing the existing large crops yield gaps is one of the appropriate approaches to meet the growing regional food security demands. Sustainable food security is a critical issue for countries in the region. As both the world's key supplier and largest consumer of food, what Asia does for its food security will have significant effects on ensuring sustainable global food security. With this realization, the Asian Development Bank (ADB), FAO and the International Fund for Agricultural Development (IFAD) joined forces to tackle widespread hunger and build food security throughout the APR and the details are available in the publication *Food For All - Investing in Food Security in Asia and the Pacific - Issues, Innovations, and Practices* (ADB, 2011).

In order to meet the demands of growing population, the agriculture in the next decade will have to sustainably produce more food from less area of land through more efficient use of natural resources with minimal impact on the environment (Hobbs et al., 2008). FAO calculated that food production must rise by 70% and most of this will have to come from increased yields per hectare of arable land (McFadyen, 2012).

The reduction of current yield losses caused by pests, including weeds, is a major challenge to agricultural production (Popp et al., 2013). Bakar (2010) rightly stated that the story of agriculture is also the story of weed interference. Weeds continue to be a perennial and constant threat to agricultural productivity, despite decades of research on development of modern weed control practices aimed at their elimination (Oerke and Dehne, 2004). Weed management has become more important today for increasing food crop productivity, keeping in view of food security and safety. The majority of the countries in the APR are developing countries and the work of weed management on farmland is generally underestimated by the public; many agricultural scientists and technologists. In this paper, we have tried to discuss the problem of weeds and their management in some select countries in the Asia- Pacific region in the background of their socioeconomic status and the challenges that are being faced in balancing food security and safety with sustainability of production systems.

i) Socio-economic status

In the world, Asia Pacific is the most populous region in which China is the most populous country followed by India (Table 1). However, by 2023 India is projected to have higher population (1456 million) compared to 1387 million of China. The population dependent on agriculture varies from as little as 2.4% in Japan to as high as 64% in Vietnam. Barring Australia, New Zealand, Japan and South Korea, in almost all the countries the population is mostly agrarian. Despite this, the contribution of agriculture to the total national GDP is less than 20% in all countries with the exception of Vietnam. This is because the majority of the farmers are small, marginal and resource poor who would mostly follow subsistence farming. About 87% of world's 500 million small holder farmers (operating less than 2 ha of crop land) are in the APR. People living below poverty line (BPL), is above 20% in Bangladesh, India, Pakistan, Philippines, Sri Lanka. China has done exceedingly well in keeping BPL population at 2.8% despite over 60% of the population dependent on agriculture. Similarly the undernourished population is over 20% in Bangladesh, India, and Pakistan. The gross trade is highest in China and Japan but the exports are higher than imports in Australia, India, Indonesia, Malaysia, New Zealand, Thailand and Vietnam.

ii) Agriculture in Asia Pacific region

India, with 169 million ha, has the highest area under agriculture in the region followed by China (Table 2). Bangladesh has the highest percentage (agricultural land to total land mass) followed by India. The lowest is with New Zealand followed by Australia. The percent irrigated area is over 50% of the cropped are in Pakistan, Sri Lanka, New Zealand, Japan, China and Bangldesh. The pesticide consumption is less than10 kg/ha in all countries except China, Japan and Philippines. The highest fertilizer consumption is noticed in New Zealand,

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Malaysia and China. The highest tractors numbers are reported from India, followed by China and South Korea.

The area, production and productivity of major food crops is given in Table 3. Rice is the main staple in the Asia and the Pacific region, providing almost 39 % of calories, followed by Wheat.Wheat is growing much faster than rice and it now makes up 19.2 percent of total calorie supply. Maize is Asia's third most important grain, but about 60 percent is now being used as animal feed. In developing Asia, rice availability is equated with food security and closely connected with political stability. Changes in rice availability and hence prices have caused social unrest in several countries, most recently during food crisis of 2008 (Timmer, 2011). The World Bank estimated that an additional 120 million people were pushed into poverty as a result of that crisis. It is often said that in Asia *Rice is Life* (Zeigler and Dobermann, 2011). The share of rice to cereals declined by 5% in South Asia and SE Asia, the decrease was over 13 % in East Asia (Table 4). Despite rapid transformation of Asian economies, agriculture remains very important. This is mostly because of large number of small farmers in Asia can not be moved to urban industrial and service jobs in just a few decades, even with rapid economic growth (Timmer, 2011). However, from a food security perspective, the overall importance of rice to Asian consumers is gradually declining (Table 5) The share of rice fell by 0.25% per year between 1960 and 1990, and by 1.00% per year from 1990 to 2007. This is an evidence of changing food habits. Open trade and globalization of tastes, there is preference for wheat, meat and dairy products, fruits and vegetables. Projecting forward, global rice consumption is expected to rise from the 441 mmt consumed in 2010 to about 450 mmt in 2012, before declining to just about 360 mmt in 2050 (Timmer, 2011). Another major force altering the food equation is shifting rural-urban populations and the resulting impact on spending and consumer and preferences. With an income growth of 5.5 %per year in South Asia, annual per capita consumption of rice in the region is projected to decline to its 2000 level by 4% by 2025. At the same time consumption of milk and vegetables is projected to increase by 70% and of meat, eggs and fish by 100 % (Kumar etal 2007).

iii) Challenges in agriculture

Feeding the increasing population is a big challenge particularly in the developing countries. According to the FAO, the food production must rise by 70% by 2015 and most of this will have to come from increased yields per hectare of arable land (McFadyen, 2012). This is most daunting considering the shrinking quantity and quality of resources, impact of globalization and changing food habits, climate change impacts, diversion of land for cultivation of crops for biofuel, industrial and urbanization demands etc.

Weeds have been one of the major constraints in production of crops. A substantial quantity of crop harvests is lost each year, due to untimely and inadequate weed control. Poor appreciation of the damage the weeds cause in crop production is most prevalent in most of the developing countries in APR. The following section discusses how better understanding of weeds and their management could help in addressing some of the challenges facing agriculture with respect to food security and food safety.

MAJOR WEEDS AND LOSSES

a) Major weeds

Weed communities of APR are floristically diverse because of variation in: agro-ecosystems in the region, seasonal crop management patterns at the farm level, spatial heterogeneity, soil type, fertility levels, water availability and other agro-ecological factors and have been adequately documented by many weed scientist from the region (Moody, 1989; Azmi and Baki, 2003; Zhang, 2003; Gogoi et al., 2005; Rao et al., 2007). Changing cropping patterns and agricultural practices have altered the floristic composition and the competition by weeds. The dominance of *Phalaris minor* in wheat- rice system (Yaduraju and Gopinath, 2005) and

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of weedy rice under direct-seeded rice cultivation (Rao et al., 2007; Chauhan, 2013) are some of the examples. Impending effects of climate change will bring in its own share of changes not only on composition of weeds, but also on the crop-weed competition and weed management.

b) Weed losses

Weeds are the main constraints in achieving higher crop production. To farmers, the most tangible losses due to weeds are those of crop yields and quality which have bearing on food security and safety, respectively. Baki, (2006) reported that those losses in the APR, range from 10 to 25%. The extent of crop yield losses due to weeds, vary depending on the crop and associated agro-ecological factors. Even with existing crop protection measures, approximately one-third yield losses occur globally (Bruce, 2012). Weeds contribute most to these losses. Global estimated loss potential of weeds in rice, wheat and maize indicate that weeds account for 46.2 % to 61.5% of potential losses and 27.3 to 33.7% of actual losses caused by all pests together (Table 6). The crop losses of Rs 900 billion (US$ 2 billion) per annum in India to insect pests, diseases and weeds (Singhal, 2008). Zhang (2003) reported that in China, weeds are responsible for an average reduction of crop yields of 12.3–16.5%.

The economic impact of weeds in Australian winter cropping systems has been estimated in terms of an economic surplus loss of $1.3 billion (Jones et al. 2005). This surplus loss represented 17% of the gross value of Australian grain and oilseed production in 1998-99, and was comprised primarily of yield losses from residual weeds and herbicide costs. Sinden et al. (2004) have reported weed losses Australian agriculture in the range of $3.4 to4.4 billion per annum.

Most estimates take in to account only the losses in yield. However, if the cost of weed management, reduced efficiency of inputs, losses in quality, disease and pest occurrences (weeds being the alternative hosts of many diseases and pests) are taken into account, the figures can be quite monumental (Baki,2004).

Given the projected increase in demand for food by 2050, sustainable ways of preventing these losses are needed. Reducing crop yield losses due to weeds is one of the most promising measures to improve food security in the coming decades.

WEED MANAGEMENT

Depending on the socio-economic conditions of the country, various methods of weed control are practiced. The objective of this paper is not to give a review of the various methods adopted in different countries. An attempt is however made to discuss some of them in the light of challenges the agriculture is facing today with respect to food security and safety.

Manual weeding is still the most predominant method of weed removal in many countries in the Asia and the pacific region. However, it is not only tedious, time-consuming and inefficient but is increasingly becoming uneconomical as well. Use of draught animals for intercultural operations is also coming down. Wages have gone up many-fold over the past two decades. In India the wages were less than $0.5 in 1970s are currently not less than $4 to $5 per person per day. In other words, one time hand weeding of an hectare rice which used to cost $10, costs now a minimum of $80. Poverty alleviation programs introduced in some countries to promote inclusive growth in economy have also contributed to the scarcity of labour for farm work. The introduction of National Rural Employment Guarantee scheme in India has been implicated for skyrocketing of wages and non-availability of labour for agricultural operations. The scheme guarantees by law 100 days of employment in a year for at least one member in the family living below poverty line (BPL). This flagship program which cost the exchequer nearly Rs 400 billion (USD 9 billion) annually has proved very successful and has benefitted a vast number of rural workforce (40 million households in 2010). Another scheme recently passed by the Indian Government- the National Food Security Bill proposes to ensure that every BPL family in the country will be entitled to 25 kg

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wheat (at Rs 3 = 5 cents) or 35 kg rice (at Rs 2 = 3.3 cents) per month. This ambitious scheme expected to cover 67 % o the population will cost the government a whopping over US$ 200 billion per annum.

As farm wages have increased due to economic growth and certain countries government policies in Asia, herbicides have increasingly been substituted for hand weeding (Naylor, 1996). 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. Between 100-200% increases in the current labor price are realistic expectations within 5-10 years (Beltran et al., 2012). Farmers are left with little choice but to reduce labor and production costs, particularly for the most labor-intensive tasks, such as manual weeding. Hence the herbicide use increased over years even in India and China (Table 7). In China, the area treated with herbicides has increased from less than one million hectares in the early 1970s to more than 60 mha in 2000 (Zhang 2001). In 1973 in China, it was estimated that rice crop losses due to weeds were 40% even though the crop was hand weeded several times. In 1988 with increased adoption of herbicides, the loss of rice to weeds was estimated at 8% (Moody, 1991).

In India, herbicides constitute 18% of the total pesticides (41,350MT) in 2004.Among field crops herbicide use in India is maximum in rice (Raju and Gangwar, 2004) and 57% area of wheat is under herbicide use in Punjab, Haryana, western Uttar Pradesh and Uttarakhand.

In Malaysia weed management is herbicide-based with no less than 70% of the pesticide market or RM276 millions annually for the past two decades (Baki, 2005). 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 (Karim et al., 2004). In Philippines,96-98% of rice farmers use herbicides. The majority of farmers supplement herbicide application with hand weeding; 35% perform one additional hand weeding while 45% do two hand weedings. Three additional hand weedings are carried out by 15% of farmers (Gianessi and Williams, 2012).

In Pakistan, about 40% area of wheat, 20% in rice, 30% each in maize and cotton and 35% in sugarcane is treated with herbicides (Marwat and Azim- personal communication). In Bangladesh, the loss in rice yield in farmers' fields due to poor weed control is reported to be 43-51% (Rashid etal, 2012). The yield gap between herbicide use and hand weeding is as high as 1mt/ha with30% of farmers losing in excess of 500 kg/ha in the absence of herbicides (Ahmed et al., 2001). Pre-emergence herbicides in rice are 38-46% cheaper than one hand weeding (Mazid et al., 2001). The herbicide application gave 116% higher net income than hand weeding due to increased yield and lower cost (Rashid et al., 2012).

In the Philippines, the proportion of rice farmers using herbicides increased from 14% in 1966 to 61% in 1974 (De Datta and Barker, 1977).Today 96-98% of Philippine rice farmers use herbicides (Beltran et al, 2012). A recent study determined that with increased labor cost, herbicide application in rice fields is superior to manual weeding even at the lowest weed density by US$ 25-54/ha (Beltran et al, 2012)). At the highest weed density and highest labor cost, herbicide application is approximately 80% (about US$ 200/ha) more profitable than hand weeding. In Korea, the rice area treated with herbicides which was 27% in 1971 (Wang, 1971), went up to 65% in 1977 and currently entire area is treated with herbicides (Kim, 1981).

The trend of using more herbicide in rice production has been observed in Vietnam. There are about 37 compounds or proprietary mixtures formulated in 79 commercial products available for use in Vietnam. Vietnam used 5,000 tons of herbicides (19.4% of total pesticides) costing US$ 18 million, with rice herbicides contributing 89%. (Tuat et al., 2002).

In Nepal, herbicide use is yet to take off with 91% of rice farmers practicing manual weeding and only about 2% reported to have used butachlor (Regmi et al., 2009). About 7% did no weeding at all, particularly in lowland fields. In wheat, *Terai* farmers generally did not weed the crop but about 59% of the farmers removed weeds manually for animal feed. Only

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17% of the farmers used chemicals and 23% did not weed. In the hills, manual weeding was a common practice with 98% of the farmers following the practice.
Herbicides worth over $1.25 billion is used in Australia each year, covering more than 90% of the cropped area of wheat, barley, oats, sorghum and canola – the important food crops in the country (Michael Widderick, personal communication). In New Zealand, the total pesticide consumption is about 3,700 MT per annum with herbicides taking the highest share (68%) followed by fungicides (24%) and insecticides (8%) (Manktelow et al., 2005). They reported that herbicide imports increased by 42%, between 1999 and 2003

CHALLENGES, OPPORTUNITIES AND IMPLICTIONS

i) Higher resource use efficiency

One of the challenges facing agriculture is to produce more with limited resources. Enormous quantities of applied nutrients are wasted through inadequate and inappropriate agricultural practices. Timely weeding is critical for healthy crop growth as it will shift crop-weed competition in favour of crop. But it is seldom practiced. The fertilizers are simply broadcasted and placement of fertilizers is seldom practiced. Same is true with irrigation. Water will be the most limiting resource for agriculture in many countries. Simple interventions such as drip irrigation or supply of water in alternative furrows would reduce weed infestation substantially. Conservation agriculture by allowing the crop residues to remain on ground not only reduces the demand for water but also reduces soil erosion. Zero tillage is another resource conservation technology which also results in saving of water by 10-15%, besides effecting 15-20 % control of the major weed - *Phalaris minor*.

Rice requires huge quantities of water. Scheduling irrigation at alternate drying and wetting (AWD) cycle will result in saving of 15-40 % water. A simple technique developed at IRRI is helping thousands of farmers in Bangladesh, Vietnam and Philippines, in recording higher profits by observing the safe interval between wetting and drying cycles (Zeigler and Dobermann, 2011).

Direct-seeding of rice (DSR) is another approach to save water, labor and energy requirement. Several experiments carried out have demonstrated that the productivity of DSR is comparable to puddle transplanted rice, if weeds are managed adequately (Rao and Ladha, 2011; Kumar and Ladha, 2011; Rao and Nagamani, 2013). However, the weed management will be great challenge under DSR, particularly the problem of weedy rice (Rao et al., 2007; Chauhan, 2013).

i) Conservation agriculture

In APR, smallholder farmers normally use tillage for the purpose of weed management and to facilitate planting of crops. However, conservation agriculture (CA) is gaining popularity word over and is considered as a sustainable method crop production. It ensures cultivation of crops with minimum or no disturbance of the soil and maintaining crop residues on the surface. In the last decade, farmers in the rice-wheat farming system in the Indo-Gangetic plain of Bangladesh, India and Pakistan have adopted minimum tillage practices widely. Since being introduced in the early 1990s, zero tillage for wheat has been adopted rapidly by more than one million farmers. Farmer's wheat yields have been reportedly improved and production costs have decreased by an average of $ 65 per hectare with additional benefits being water conservation, saving of fossil fuel and reduced use of herbicides. However, there are issues that need to be addressed with respect to effective weed management. The performance of herbicides and integration of mechanical methods are the key ones.

Australian grain growers have been reducing their use of cultivation since the 1970s with 44% of the nation's crop in no-till by 2001 (D'Emden and Llewellyn 2006). The falling price of the predominant knockdown herbicide, glyphosate, had a significantly positive effect on the adoption of no-till with 78% of the farmers practicing no-till in 2008. The use of no-till means that the seed is sown with minimum soil disturbance, reducing evaporation and

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increasing yields. In addition, no-till systems allow for earlier planting. Research demonstrated that using herbicides instead of tillage resulted in 27 mm of extra water in the soil profile and an increase in grain yields of 15-25% (Wylie, 2008). Agricultural green house gas (GHG) emissions can be curbed by decreasing fuel use by field equipment. Each gallon of diesel fuel burned by a tractor is estimated to release 10,180 grams of CO2 (EPA, 2011). In a wheat-fallow system in semi-arid subtropical Queensland, Australia, practicing zero tillage reduced fossil fuel emissions from machinery operation by 2.2 million g CO2/ha over 33 years or 67 kg CO2/ha/year (four to five tillage operations with a chisel plough to 10 cm during fallow each yearwere replaced by one herbicide spray).

ii) Organic agriculture

Organic food is increasingly being sought after by the health conscious public even at the cost of higher market prices. Weed management is a great challenge in organic farming. Acute shortage of labour, higher wages, unavailability of draught animals have made non-chemicals methods uneconomical. Further, in many countries of the Asia and the Pacific, wherein view of population pressure, increasing food production is priority, practicing organic agriculture on a large scale is highly unrealistic. The problem is much more serious in advanced countries like Australia, New Zealand and Japan. Non-chemical methods such as flaming, steaming, and new implements with sophisticated machine guidance and weed detection technologies are used for managing weeds. Use of a single biocontrol agent to control a wide variety of weeds is impossible. Designer crops which resist weeds is not in sight yet. Similarly, research on allelopathy, despite pursuing it for many years, has not yielded any practical solution till date.

iii) Climate change

Global climate change is a topic of serious discussion world over. There are many studies to indicate that the climate change would impact agriculture in a big way. Climate change manifested by droughts, floods, rise in sea levels etc would affect cropping pattern and crop productivity. Cereal yields are set to decrease up to 30% by 2050 in South Asia, in East Asia, for 10 raise in temperature expected by 2020s, water demand for irrigation would increase by 6-10% or more. Around 12 per cent of GHG emissions come from agriculture and the Asia-Pacific is responsible for around 40% of global agricultural emissions (Rosegrant et al., 2008). The APR is likely to face the worst impacts on cereal crop yields. Loss in yields of wheat, rice and maize are estimated in the vicinity of 50%, 17%, and 6% respectively by 2050 (http://www.ifpri.org/publication/impact-climate-change-agriculture-factsheet-asia). This yield loss will threaten the food security of at least 1.6 billion people in South Asia.

Very limited research has been conducted on weeds and their management under climate change in APR. Under elevated CO2, changes in temperature and precipitation patterns, both weeds and crops may be affected similarly depending on their photosynthetic pathway. It may be noted that 14 of the world's worst weeds are C4 plants (Holm et al. 1977), while around 76% of the harvested crop area in 2000 were grown with C3 crops (Monfreda et al. 2008). If the hypothesis is right that C3 crops would benefit more from elevated CO2 than C4 weeds, losses due to C4 weeds might decrease (Patterson and Flints 1980; Coleman and Bazzaz 1992; Ziska 2003). However, high temperatures due to global warming may decrease reproductive output despite an increase in CO2. In drought situations C4 weeds might also have advantages over C3 crops under elevated CO2 (Ward et al. 1999). C4 crops might out-compete better growing C3 weed in drought situations, and at higher temperatures utilizing mycorrhiza (Tang et al. 2009).

Much more research is needed to understand different factors involved in the climate change and their effect on crops, weeds and crop weed competition and weed control measures. Development of crop and weed management practices that are better adapted to changing climate is important for food security in the Asia - Pacific region.

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iv) Alien invasive weeds

Globalization-increased trade, tourism and travel has enhanced the risk of introduction of alien invasive weeds. The negative impacts of such invasions on biodiversity, environment, agriculture and health of humans and animals is well documented. The total loss to the world economy as a result of invasive non-native species has been estimated at 5% of annual production (Pimentel et al. 2001).The total annual cost of dealing with INS worldwide is estimated to be in the hundreds of billions of dollars, including costs of control, detrimental effects on human health and losses in agricultural production and ecosystem services (Sastroutomo and Hong, 2007).

An estimated 20-30% of all introduced species worldwide cause a problem (Pimentel et al. 2001). List of invasive weed species of Australia (DiTomaso, 2012), India (Reddy, 2008), Malaysia (Baki, 2004), Indonesia (Tjitrosoedirdjo, 2005), China (Xu, 2012);tropics (Yaduraju and Kathiresan, 2003); pacific (Sherley, 2000) and south and south east Asia (Pallewatta et al., 2003) are available. Several recent studies have been undertaken to estimate the economic impact of INS in a number of countries, which indicate that the cost of INS to a country's economy can be very high, but the estimates vary widely.

A synthesis of literature (Ziska and George, 2004) on impact of climate change on invasive weeds indicated that: a) invasive, noxious weeds on the whole have a larger than expected growth increase to both recent and projected increases in atmospheric CO2 relative to other plant species, b) rising CO2 can preferentially select for invasive, noxious species within plant communities; c) initial observations suggesting that control of such weeds may be more difficult in the future.

Yaduraju and Kathiresan (2003) attempted to identify the number of potential invaders in some of the countries in the APR. Matsui et al. (2005) have developed an internet data base to facilitate sharing of information among countries in the APR Asian and Pacific region, and to easily accumulate and search data on various species existing in each country. Thus the measures such as establishing early-warning mechanism, strengthening the management of invasive species and quarantine of alien species, establishing scientific system of introduction and improving people awareness are necessary to control the invasion of non native weed species.

The first line of defence against invasion is prevention, which by and large depends on legislation backed up by inspection procedures. But, unfortunately this has not been put into practice in many countries with the exception of Australia and New Zealand. The developing countries in the region should seek help from these two countries in capacity building in weed risk analysis and other relates issues. It has been reported from Australia, that every dollar spent on prevention activities, between \$ 25.60 to 38.30 of benefits are provided (Table 8). Based on these findings, the estimated expenditure of \$ 46.0 m million on weed management initiatives in 2005-06 is expected to generate a net benefit overall to Queensland of between \$152 and 249 million. It is time other countries generate such data to impress the policy makers.

v) Herbicide resistant weeds

Herbicide resistance is a global phenomenon. The incidence of resistant weeds is more in developed countries like Australia, where herbicides have been in use for long. Among crops, wheat and rice have more herbicide resistant weeds than maize. The shift in method of rice establishment to direct-seeding, increased herbicide use and continuous use of similar herbicides is resulting in weeds resistance in rice of developing countries also.

Herbicides with novel modes of action are needed to combat the evolution of resistance to currently available herbicides (Kim, 2001). As the extent and cost of herbicide-resistant weed populations increases, farmers are being urged to invest in practices to prevent, or at least delay, further resistance development.

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vi) Herbicide tolerant crops (HTCs)

Genetically modified crops have become extremely popular since their introduction in 1996. Currently grown on over 170 mha area in 29 countries involving over 17 million farmers of which about 15 million are small and resource poor (ISAAA, 2012). Tolerance to herbicides is the most predominant trait contributing nearly 70% of the total area. India with 10.8 mha and China with 4.0 mha are ranked 5th and 6th in terms of total area under GM crops. Pakistan, Philippines, Australia and Myanmar are the other countries in the region growing GM crops. However, herbicide tolerant crops (Cotton & Canola) are cultivated only in Australia. Despite the predominance of HTCs in USA, Brazil, Argentine and Canada, they have not yet been commercialized in other Asian countries. In India, despite the strong support by the academia, approvals for GMCs including HTCs, are facing stiff opposition by the anti-GM groups. However, with the proposed introduction of Golden rice in Philippines and Indonesia and of bio-tech maize in China, the GM crops adoption prospects in Asia look brighter (ISAAA, 2012).

There is strong resistance to the technology in several countries. The impact of HTCs on biodiversity, development of super weeds and health risks are the major apprehensions coming in the way of their commercialization. There is ample evidence to demonstrate that the technology has indeed helped in recording yield increases- mostly realized due to better weed management. Safety of GM foods is again an issue hotly debated. But in USA- the country with the largest area under GM crops- consumption of GM food for over 16 years has not led to any health issues. The protagonists argue that GM crops would indeed auger well to deal with food security and safety.

Clearfield rice - a imidazolinone (IMI) resistant rice derived from conventional breeding technique, has been in cultivation in Malaysia mainly for managing weedy rice (Sudianto et al., 2013). 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 herbicide following introgression of resistant gene from the HT rice are the major concerns that need to be addressed adequately. The risk of gene transfer may be higher in the centre of origin of a crop or when the crop and a related weed species are grown under a cropping system which promotes evolutionary selection (Mallory-Smith 2000). These are the reasons why release of GM soybean in east Asia and rice in India and China might be a danger where these crops have originated (Kim, 2001). Weed science community should engage in awareness and educational activities involving the public and other stakeholders and influence policy makers in taking informed decisions.

CONCLUSIONS

"The Asia and the Pacific region is still home to some 578 million hungry people, approximately two-thirds of the world's hungry, so it is high time to move out of comfort zones and forge new partnership, collaborative arrangements and net works with the single objective of achieving food for all", said ADB president Haruhiko Kuroda (ADB, 2011). "Gross annual investments of $ 120 billion are required for primary agriculture and downstream services- in a responsible manner and focussed on rural areas through pro-poor programs and livelihood activities for poor and small farmers" - Said Diouf, the Director General of FAO.

The scientific solutions used in the developed world may not suit the vast majority of the developing countries in the APR. Hence new location specific strategies and approaches are to be evolved in APR.. Creating awareness is urgently needed among the vast majority of farmers, extension personnel and the insensitive administrators and policy makers, regarding the losses caused by weeds and the need for weed management at the critical period. The inadequate capacity of the extension staff needs to be alleviated by proper training of the trainers. The region has wealth of innovative technology and good practices- along with an

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abundance of natural and human resources. The challenge is how to harness and channelize these assets to ensure food security and safety to all, through better weed management and optimised crop productivity. In addition to chemical component, future research emphasis must be made equally on several non-chemical components of integrated weed management, which are neglected by public research institutes and are of not interest to private sector. Networking and collaboration with weed scientists from the developed countries in the region as well as from the other parts of the world are to be encouraged for evolving optimal weed management solutions to meet the food security and safety needs. Future weed management strategies for Asian pacific region should take in to consideration the present and future economic, social, and environmental concerns for reducing the detrimental effects of existing and invading weed species on food security and food safety.

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Table 1. Agricultural development in Asia Pacific region (2009)

Country	Total Population (million)	Population dependent on Agriculture (%)	Agri. GDP (%)	Agri. Trade (billion US$)		Urbanization (%)	BPL (%)
				Import	Export		
Australia	22.0	4.0	2.5	7.8	23.6	97	12.8
Bangladesh	151.0	47.2	19.0	3.9	0.3	26	40.0
China	1336.0	62.0	12.1	59.2	32.2	37	2.8
India	1189.0	49.3	17.5	7.8	16.7	28	25.0
Indonesia	245.0	38.6	14.4	8.6	17.7	42	13.3
Japan	126.0	2.4	1.4	46.0	2.3	79	15.7
South Korea	48.0	5.2	2.5	14.9	2.6	83	15.0
Malaysia	29.0	13.0	10.2	8.9	17.7	58	5.1
New Zealand	4.4	8.0	5.6	2.6	13.5	86	NA
Pakistan	176.0	43.6	20.4	3.7	2.0	33	24.0
Philippines	101.0	34.7	14.9	5.6	3.1	59	32.9
Sri Lanka	22.0	43.8	13.4	1.6	1.2	23	23.0
Thailand	67.0	42.6	11.6	5.1	18.0	20	9.6
Vietnam	87.0	64.0	22.1	4.5	5.6	25	11.0

DES: Dietary Energy Supply

Source:

1. Selected Indicators of Food and Agricultural Development in the Asia-Pacific Region 1999-2009.

2. http://www.nationmaster.com/

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Table 2. Agricultural statistical data of Asia-Pacific countries

S. No.	Country	Agricultural land (million ha)	Irrigated land as % of Agricultural land	Consumption (kg/ha)		Agricultural Tractors ('000 Numbers)
				Pesticides	Fertilizers	
1.	Australia	44.4 (5.8)*	5.7	8.0	34	315
2.	Bangladesh	8.7 (66.8)	58.0	9.8	165	5
3.	China	122.5 (13.1)	52.3	27.6	468	2064
4.	India	169.3 (56.9)	36.8	6.6	189	3149
5.	Indonesia	37.1 (20.5)	18.1	3.0	189	70
6.	Japan	4.6 (12.7)	54.4	26.5	278	2028
7.	South Korea	1.7 (18.0)	47.6	13.4	480	244
8.	Malaysia	7.6 (23.1)	4.8	4.0	930	43
9.	New Zealand	0.5 (2.0)	82.0	4.7	1720	77
10.	Pakistan	21.2 (27.5)	93.7	2.5	163	470
11.	Philippines	10.3 (34.5)	14.8	18.0	131	63
12.	Sri Lanka	2.2 (35.1)	84.0	0.9	284	22
13.	Thailand	18.8(37.0)	34.0	2.1	131	830
14.	Vietnam	9.4 (30.4)	48.9	2.0	287	163

* Percentage of total land area

Source:

FAO Statistical Yearbook 2013

Selected Indicators of Food and Agricultural Development in the Asia-Pacific Region 1999-2009.

http://www.fao.org/nr/aquastat

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Table 3. Food grain production and Productivity of Asia-Pacific Countries (2010)

S.No.	Country	Rice			Wheat			Maize			Pulses			Oil crops		
		A	**P**	**Y**	**A**	**P**	**Y**	**A**	**P**	**Y**	**A**	**P**	**Y**	**A**	**P**	**Y**
1	Australia	0.02	1.90	9.5	13.51	22.14	1.6	0.07	0.399	5.7	1.75	1.92	1.1	2.05	1.03	0.5
2	Bangladesh	11.8	49.35	4.2	0.38	0.91	2.4	0.22	1.32	6.0	0.24	0.22	0.9	-	-	-
3	China	30.12	197.22	6.5	24.25	115.18	4.7	29.88	164.34	5.5	2.79	4.47	1.6	27.98	16.19	0.6
4	India	36.95	120.62	3.3	28.52	80.71	2.8	8.30	19.92	2.4	26.17	18.32	0.7	37.44	11.23	0.3
5	Indonesia	13.24	66.41	5.0	-	-	-	4.00	16.4	4.1	0.26	0.33	1.1	9.53	26.70	2.8
6	Japan	1.63	10.6	6.5	0.21	0.88	4.2	<0.01	0.027	2.7	0.04	0.09	2.2	-	-	-
7	South Korea	1.46	8.23	5.4	<0.01	0.03	4.1	0.02	0.102	5.1	0.24	0.20	0.9	-	-	-
8	Malaysia	0.67	2.55	3.8	-	-	-	<0.01	0.052	5.2	-	-	-	4.25	19.12	4.5
9	New Zealand	-	-	-	0.04	0.32	8.1	0.02	0.224	11.2	0.01	0.03	2.9	-	-	-
10	Pakistan	2.36	7.23	3.1	9.13	23.73	2.6	1.05	3.57	3.4	1.47	0.83	0.6	3.30	0.99	0.3
11	Philippines	4.35	15.77	3.6	-	-	-	2.66	6.916	2.6	0.08	0.06	0.8	3.55	2.13	0.6
12	Sri Lanka	1.06	4.3	4.1	-	-	-	0.05	0.11	2.2	0.02	0.02	1.0	-	-	-
13	Thailand	10.99	31.6	2.9	<0.01	1.00	1.0	1.04	4.264	4.1	0.18	0.17	0.9	1.08	1.73	1.6
14	Vietnam	7.51	40.00	5.3	-	-	-	1.12	4.48	4.0	0.40	0.40	1.0	-	-	-

A: Area in million ha. **P:** Production in million tonnes **Y:** Yield in tonnes per ha.

Source: FAO Statistical Yearbook 2013; Selected Indicators of Food and Agricultural Development in the Asia-Pacific Region 1999-2009.

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Table 4. Rice in Asian Agriculture

Category	Rice as % of Cereal Production			Rice as a % of Agriculture		
	1961	1980	2007	1961	1980	2007
World	24.6	25.6	28.1	5.3	6.2	6.0
East Asia	56.2	53.2	43.0	18.9	20.2	8.3
South Asia	60.9	56.7	55.2	20.0	19.8	15.2
Southeast Asia	90.6	88.2	85.9	40.2	37.6	32.0
Africa	9.3	11.9	15.2	1.5	1.9	2.3

Source: Timmer, (2011).

Table 5. The changing role of rice in food consumption (Calories from Rice as % of total)

Country	1970	1990	2007
Bangladesh	75.1	75.2	69.8
China	38.7	33.4	26.8
India	32.4	35.2	29.9
Indonesia	54.8	55.2	48.8
Republic of Korea	48.6	35.6	26.8
Philippines	43.3	40.6	49.6
Vietnam	69.2	72.6	57.8

Source: Timmer, (2011).

Table 6. Global estimated loss potential and actual loss due to weeds in three major crops of Asia Pacific Region.

Crop	Total loss due to all pests %		Loss due to Weeds			
	Potential	Actual	Potential	% of total pests loss	Actual	% of total pests loss
Wheat	49.8 (44-54)	28.2 (14-40)	23.0 (18-25)	46.2	7.7 (3-13)	27.3
Rice	77 (64-80)	37.4 (22-51)	37.1 (34-47)	48.2	10.2 (6-16)	27.3
Maize	65.8 (58-75)	31.2 (18-58)	40.3 (37-44)	61.5	10.5 (5-19)	33.7

Source: Oerke,(2006).

Table 7. Global rice herbicide sales (million US$), selected years

.Region	1980	1988	1996	2007
Japan	459	753	703	490
China	19	11	51	125
Republic of Korea	15	37	117	84
India	15	26	28	50
Rest of world	119	219	196	436
Total	741	1,169	1,363	1,343

Source: Norton et al (2010).

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Table 8. Estimated benefit cost ratios for various weed management programs in Queensland, Australia

	Activity	**BCR range (%)**
1	Prevention	25.6 – 38.3
2	Eradication (Siam weed as a test case)	9.9 – 26.8
3	Control (*Acasia*, Rubber wine & Mesquite as case studies)	1.7 – 3.1
4	Research (ex: *Parthenium hysterophorous)*	13.9 -24.4
5	Education & awareness (Weed Buster)	8.0 -79.9
6	Environmental weeds	1.1 – 1.8

Source: Sinden et al, (2004).

LITERATURE CITED

ADB (Asian Development Bank). 2011. *Food for All: Investing in Food Security in Asia and the Pacific–Issues, Innovations, and Practices*. ADB, Mandaluyong City, Philippines.

Ahmed G.J.U., Hassan M.A., Mridha A.J., Jabbar M.A., Riches C.R., Robinson E.J.Z., Mortimer M. 2001. Weed management in intensified lowland rice in Bangladesh. *Proc. BCPC Conference, U.K.*, pp. 205-210.

Azmi M. and Baki B.B. 2003. Weed species diversity and management practices in the SekinchanFarm Block, Selangor's South West Project—a highly productive rice area in Malaysia. *Proc. 19th Asian-Pacific Weed Sci. Soc. Conf. 17-21 March 2003, Philippines***1**:174-184.

Bakar B.B. 2010. Shaping the future of weed science to serve the humanity in the Asia Pacific. *Pak. J. Weed Sci.,***16**: 123-138.

Baki B.B. 2006. *Weed Science in the Service of Humanity*. University of Malaya Press, Kuala Lumpur, Malaysia, 178p.

Baki H.B., 2004. Invasive weed species in Malaysian agro-ecosystems: Species, impacts and management. *Malaysian J. Sci.***23**: 1-42.

Beltran J.C., Pannell, D.J. and Doole, G.J. 2012.Economic implications of herbicide resistance and high labour costs for management of annual barnyard grass (*Echinochloa crus-galli*) in Philippine rice farming systems. *Crop Prot.* **31**: 31–39

Bruce T.J. 2012. GM as a route for delivery of sustainable crop protection. *J Exp Bot.,***63:** 37-41

Chauhan B.S. 2013. *Management strategies for weedy rice in Asia*. International Rice Research Institute (IRRI), Manila, Philippines.

Coleman J.S. and Bazzaz, F.A., 1992. Effects of CO2 and temperature on growth and resource use of Co-occurring C3 and C4 annuals. *Ecology***73:** 1244-1259.

DiTomaso J.M. 2012. Invasive plant threats and prevention approaches in the asia-pacific region and united states. *Pak. J. Weed Sci. Res.* **18:** *187-197*

De Datta S.K. and Barker, R. 1977. Economic evaluation of modern weed control techniques in rice. In: *Integrated Control of Weeds. J.D. Fryer and S. Matsunaka (eds.).* University of Tokyo Press, Tokyo.

EPA. 2011.*Greenhouse Gas Emissions from a Typical Passenger Vehicle*. Office of Transportationand Air Quality. EPA-420-F-11-041. December.2011.

Gianessi L. and Williams A**.** 2012.Increasing Cost of Labor in the Philippines Promotes Herbicide Applications in Rice. *International Pesticide Benefits Case Study No. 56,* CropLife Foundation**,** Crop Protection Research Institute, Washington**,** U.S.A.

Gogoi A.K., Yduraju N.T. and Dixit A. 2005. *District-wise Distribution of Major Weeds in India*. National Research Center for Weed Science, Jabalpur, India.

Hobbs, P.R., Ken Sayre and Raj Gupta. 2008.The role of conservation agriculture in sustainable agriculture**.** *Philosoph. Trans R Soc. Lond. B. Biol Sci.***363:** 543–555.

ISBN: 978-602-96519-2-8

Holm, L., D. Plucknett, J. Pancho, and J. Herberger. 1977. *The World's Worst Weeds: Distribution and Biology.* University of Hawaii Press, Honolulu. xii + 609 pp.

ISAAA, 2012.http://www.isaaa.org/resources/publications/briefs/44/executivesummary/

Jones R.E., Vere D.T., Alemseged Y. and Medd R.W. 2005. Estimating the economic cost of weeds in Australian annual winter crops. *Agric. Econs.* **32:** 253-265.

Karim S.M. R., Azmi, B.M. and Ismail, B.S. 2004. Weed problems and their management in ricefields of Malaysia: An overview. *Weed Biol. Mgn*t. **4:** 177–186.

Kim K.U. 2001.Trends and expectations for research and technology in the Asia Pacific region. *Weed Biol. Mgn*t. **1:** 20-24.

Kim K.U. 1981. Weed control in Korea. In: *Weeds and weed control in Asia*. FFTC Book Series No. 20, Taipei, Taiwan.

Kumar V. and Ladha J.K. 2011. Direct-seeded rice: recent developments and future research needs. *Adv. Agron.* **111**: 297-413.

Kumar P., Mruthyunjaya, and P.S. Birthal. 2007. Changing composition pattern in South Asia. In: *Agricultural Diversification and Smallholders in South Asia. P.K. Joshi, A. Gulati, R. Cummings Jr. (eds.).* New Delhi: Academic Foundation.

Llewellyn, R.S. and D'Emden, F.H, 2009.No-tillage adoption decisions in southern Australian cropping and the role of weed management. *Aust. J. Exp. Agric.* **46**, 563-569

Mallory-Smith, C.A. 2000. Introgression: occurrence vs. consequence. *3rd Intl. Weed Sci. Cong. Abstr.* p. 166.

Manktelow D., Stevens P., Walker J., Gurnsey S., Park N., Zabkiewicz J., Teulon D. and Rahman A. 2005. *Trends in Pesticide Use in New Zealand: 2004.* Report to the Ministry for the Environment, Project SMF4193, Ministry for the Environment, New Zealand .

Matsui M., Nishiyama, K., Ogawa, Y., Shiomi, T., Konuma, A. and Yasuda, K. 2004. Development of the Asian–Pacific Alien Species Database (APASD). *Proc. Intl. Workshop Devnt. Database for Biol. Invasion in the Asian and Pacific Region. Taichung, Taiwan,* pp. 44-45

Mazid M.A., Jabbar M.A., Riches C.R., Robinson E.J.Z., Mortimer M. and Wade L.J. 2001.Weed management implications of introducing dry-seeding of rice in the Barind Tract of Bangladesh. *Proc. BCPC Conf. U.K.,* pp. 211-216.

McFadyen, R.E.C. 2012. Food security for a 9 billion population: more R&D for weed controlwill be critical, pp. 306-309. *Proc.18th Australasian Weeds Conf.* Weed Society of Victoria Inc., *Australia*.

Monfreda,C.,Ramankutty,N.,Foley,J.A.,2008.Farmingtheplanet:2.Geographicdistribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Glob.Biogeoch. Cycles***22**: 1–19.

Moody K, 1991.*Weed Management in Rice*. *CRC* Handbook of Pest Management in Agriculture,**3**: 301-328

Moody K. 1989. *Weeds Reported in Rice in South and Southeast Asia*. International Rice Research Institute (IRRI), Manila, Philippines. 442 pp.

Norton G.W., Heong K.L., Johnson D.E. and Savary S. 2010.Rice pest management: issues and Opportunities. In: *Pandey S., Byerlee D., Dawe, D., Dobermann, A., Mohanty S., Rozelle, S. and Bill Hardy, B (eds.). Rice in the Global Economy: Strategic ~Research and Policy Issues for Food Security.* Los Baños (Philippines): International Rice Research Institute, pp. 297-332.

Oerke E.C. 2006. Crop losses to pests. The Journal of Agricultural Science, 144: 31-43.

Oerke E.C. and Dehne H.W. 2004. Safeguarding production – losses in major crops andthe role of crop protection. *Crop Prot*. **23**: 275-285.

Pallewatta N., Reaser J.K. and Gutierrez A.T. (eds). 2003. *Invasive Alien Species in South-Southeast Asia: National Reports and Directory of Resources*. Global Invasive Species Programme, Cape Town, South Africa.

ISBN: 978-602-96519-2-8

Patterson D.T. and Flint E.P. 1980. Potential effects of global atmospheric CO2enrichment on the growth and competitiveness of C3and C4weed and crop plants. *Weed Sci*. **28:** 71–75.

Pimentel D., McNair S., Janecka J., Wightman J., Simmonds C., O'Connell C., Wong E., Russel L., Zern J., Aquino T., Tsomondo T. 2001. Economic and environmental threats of alien plant, animal, and microbe invasions. *Agric. Ecosyst. & Environ.***84**: 1-20.

Popp J., Peto K. and Nagy J. 2013**.** Pesticide productivity and food security - A review. *Agron. Sustain. Devnt*. **33**: 243-255

Raju R.A. and Gangwar, B. 2004. Long term effects of herbicide rotation on weed shift, crop efficiency and energy productivity in rice (*Oryza sativa*)-rice system. *Indian J. Agron.***49:** 213-217.

Rao A.N. and Ladha J.K. 2011. Possible approaches for ecological weed management in direct-seeded rice in a changing world. *Proc. 23rd Asian-Pacific Weed Sci. Soc. Conf., 26-29 September 2011, The Sebel, Cairns, Australia*, pp. 444-453.

Rao A.N. and Nagamani A. 2013.Eco-efficient weed management approaches for rice in tropical Asia. *Proc. 4th Tropical Weed Science Conference 2013.Weed Management and Utilization in the Tropics. January 23-25, 2013, Chiang Mai, Thailand.* , pp. 78-87.

Rao A.N., Mortimer A.M., Johnson D.E., Sivaprasad, B. and Ladha, J.K. 2007. Weed management in direct-seeded rice. *Advances Agron***. 93:**155-257

Rashid M**.**H**.,** Alam, M.M., Rao, A.N. and Ladha J.K.. 2012. Comparative efficacy of pretilachlor and hand weeding in managing weeds and improving the productivity and net income of wet-seeded rice in Bangladesh. *Field Crops Res*.**128**:17-26.

Reddy C.S. .2008. Catalogue of invasive alien flora of India. *Life Sci. J*.**5**: 84 – 89

Regmi A.P., Tripathi, J., Giri, G.S., Bhatta, M.R., Sherchan, D.P., Karki, K.B., Tripathi, B.P.,Virender Kumar, and Ladha, J.K. 2009. Improving food security through integrated crop and resource management in the rice-wheat system in Nepal. In *Ladha JK, Yadvinder-Singh, Erenstein O, Hardy B. (eds.). Integrated crop and Resource Management in the Rice-Wheat System of South Asia.* Los Baños (Philippines): International Rice Research Institute, pp. 177-195.

Rosegrant M.W., Ewing M., Yohe G., Burton I., Huq S. and Valmonte-Santos R. 2008. *Climate Change and Agriculture.* Deutsche GesellschaftfürTechnischeZusammenarbeit (GTZ) GmbH, Germany.

Sastroutomo S.S. andHong, W.L.*Managing Invasive Alien Species in the Asia-Pacific Region: Information Initiatives for Better Decision-making.*RAP Publication 2007 No. 02 pp. 97-106. CAB International, South East Asia Regional Centre, P.O. Box 210, 43400 UPM Serdang, Selangor, Malaysia.

Sherley, G (Ed.). 2000. *Invasive Species in the Pacific: A Technical Review and Draft Regional Strategy.* South Pacific Regional Environment Programme. Apia, Samoa.

Sinden J., Jones R., Hester S., Odom D., Kalish C., James R., Cacho, O. 2004. *The Economic Impact of Weeds in Australia.* Cooperative Research Centre for Australian Weed Management, Australia.

Singhal, S. 2008. The imperative of crop protection for farmers. In: *Dhawan, V. (ed.) Agriculture for Food Security and Rural Growth.*Tata Energy Research Institute, Teri, India, pp. 139-157.

Sudianto E., Beng-Kah S., Ting-Xiang N., Saldain N.E., Scott R.C. and Burgos N.R. 2013. Clearfield rice: Its development, success, and key challenges ona global perspective. *Crop Prot.***49**: 40-51

Tang J., Xu L., Chen X. and Hu S. 2009. Interaction between C4 barnyard grass and C3 upland rice under elevated CO2: Impact of mycorrhizae. *Actaoecologica***35**: 227- 235.

Timmer C.P. 2011. The changing role of rice in Asia's food security. In: *Food For All - Investing in Food Security in Asia and the Pacific Issues, Innovations, and Practices. ADB, Mandaluyong City, Philippines,* pp.72-93.

ISBN: 978-602-96519-2-8

Tjitrosoedirdjo S.S. 2005. Inventory of the invasive alien plant species in Indonesia**.** *Biotropia***25**: 60 – 73

Tuat N.V., Cung H.A., Tan N.T., Son N.H. 2002. Weeds in lowland rice and control methods. In: *Luat, N.V., Quyen, M.V., Dich, T., Thinh, L.K. "Rice in Vietnam in 20th Century".* Agriculture Publishing House, Vietnam.

Wang I.K. 1971. *Diffusion and Acceptance of Recommended Farm Practices for Increased Food Production.* College of Agriculture, Seoul National University. Korea.

Ward J. K., Tissue, D.T., Thomas R.B. and Strain B.R. 1999. Comparative responses of model C3 and C4 plants to drought in low and elevated CO2. *Global Change Biol.* **5:** 857-867.

Wylie P. 2008. *High Profit Farming in Northern Australia*. Grains Research and Development Corporation, Australia.

Xu H., Qiang S., Genovesi P., Ding H., Wu J., Meng L., Han Z., Miao J., Hu B., Guo J., Sun H., Huang C., Lei J., Le Z., Zhang X., He S., Wu Y., Zheng Z., Chen L., Jarošík V. and Pyšek P. 2012. An inventory of invasive alien species in China.*NeoBiota,***15**: 1–26.

Yaduraju N. and Gopinath K.A. 2005. *Little seed Canary grass (Phalaris minor Retz): Agro-ecology and management*, NRC for weed Science, Jabalpur,India, PP. 115.

Yaduraju N.T. and Kathiresan R.M. 2003. Invasive Weeds in the tropics. *Proc. 19thAsian Pacific Weed Sci. Soc. Conf., Manila. Philippines* **1**:59-68.

Zeigler R.S. and Dobermann A. 2011. A global rice science partnership. In *Food For All - Investing in Food Security in Asia and the Pacific Issues, Innovations, and Practices.* ADB, Mandaluyong City, Philippines, pp.106-116.

Zhang Z.P. 2003.Development of chemical weed control and integrated weed management in China. Weed Biol. Mgnt. **3**:197-203**.**

Zhang Z.P.2001. Weed management in rice in China. *Summary presented at FAO Workshop on Echinochloa spp. Control, Beijing, China, 27 May, 2001*. FAO, Rome.

Ziska L.H. 2003. Evaluation of the growth response of six invasive species to past, present and future carbon dioxide concentrations. *J. Exp. Bot*. 54: 395–404.

Ziska L.H. and George K. 2004. Rising carbon dioxide and invasive, noxious plants: potential threats and consequences. *World Resource Rev*.**16**: 427-447.

ISBN: 978-602-96519-2-8