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MANAGING SOIL RESOURCES
TO MEET THE CHALLENGES TO MANKIND

# Managing Soil Resources To Meet the Challenges to Mankind: Presidential Address

ISSS AISS IBG

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# Managing Soil Resources to Meet the Challenges to Mankind: Presidential Address

J.S. KANWAR*

YOUR excellencies, distinguished soil scientists, delegates, ladies and gentlemen, I have great pleasure in welcoming you to the 12th International Congress of Soil Science. At the outset I must say how grateful we are to the Government of India, Department of Agricultural Research and Education, the Indian Council of Agricultural Research and the Indian Society of Soil Science for inviting us to hold the 12th International Congress of Soil Science in this historic city of New Delhi and to the President of India for inaugurating it. Those of you who attended the 11th Congress in Edmonton, Canada, will recall that the date and venue of this Congress were announced at that time.

You are aware that the theme of this Congress is 'Managing Soil Resources to Meet the Challenges to Mankind'. The theme was selected because today we are faced with many challenges: while some developing countries have to produce more food, fibre and fuel from less and less land, the developed countries are more threatened with the serious problem of environmental degradation through industrialisation. The whole world is concerned with the global problems of hunger, malnutrition and the quality of life now and in the future. If current land-use practices continue, a child born today has less chance of getting adequate food to eat, space to live in and pure air to breathe. Therefore there is an urgent need for careful consideration and thoughtful planning of the uses of agricultural resources, particularly land.

The first International Soil Science Congress met in 1927 in the boom period which followed soon after the First World War. The second and third Congresses were held during the period of economic depression that followed. After the Second World War, a new era in science began, with greater emphasis on use of science and technology for peace and the prosperity of the human race. Its impact was felt in agriculture through scientific research in soil science, fertiliser use, water, crop and range management—either to increase production from the land already under the plough or to bring new areas under cultivation and improve the productivity of lands which were considered infertile and poor. This led to dramatic increases in yield and production in many countries, particularly the industrialised countries which

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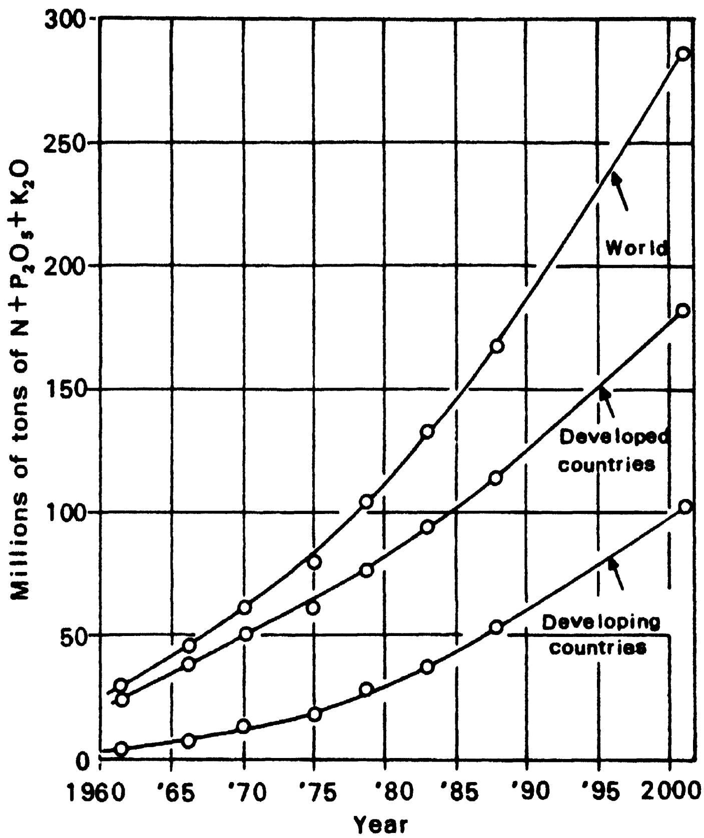


Fig. 1. World fertiliser use : projections by UNIDO

hazards arising from over-use and poor management of pesticides and fertilisers.

## Challenges to Mankind — The Theme

The 12th Congress is meeting at a time when the world has four times as much population to feed as it had at the time of the First International Meeting of Pedologists in 1909 which led to the foundation of the International Society of Soil Science in 1924. We are meeting at a time when the foodgrain exporters of the previous era have become net importers of grain; when the developing world has an expected shortage of 121 to 143 million tonnes of food in less than a decade from now(IFPRI 1977), probably more in less than two decades. We are meeting at a time when we see clouds of severe famines of food, water, fuel and energy gathering. Environmentalists are warning us of rising temperature, increasing carbon dioxide concentration and pollution of the atmosphere and of water. Our hopes of extending large-scale capital-intensive arable food farming, based on systems developed in temperate regions, to the lowland humid tropics of Africa and Central and South America, where extensive areas still remain unexploited, have not been realised. In fact such ventures have led to considerable land capitalised quickly on the advances in soil and crop sciences. The use of machinery, fertiliser and hybrid corn became the symbols of progress.

In the industrialised nations, 92% of the increased production between 1961 and 1980 came from higher yields and only 8% from area increase, whereas in Africa and Central and South America over the same period, 52 and 54% of increased production came from area expansion; Asia lay between the two extremes (Barr 1981; Table 1). Fertiliser consumption everywhere rose

**Table 1.** Sources of growth in total grain production 1961-62 to 1979-80.

| Region | Annual compound growth rate (%) change | Annual compound growth rate (%) change due to | |
|---|---|---|---|
| | Production | Area change | Yield change |
| World | 2.7 | 18 | 72 |
| Developed countries* | 2.5 | 8 | 92 |
| Developing countries | 3.0 | 27 | 73 |
| Central & South America | 3.7 | 54 | 46 |
| Africa | 2.1 | 52 | 48 |
| Middle East | 2.5 | 20 | 80 |
| South Asia | 2.6 | 20 | 80 |
| India | 2.5 | 25 | 75 |
| East Asia | 3.1 | 45 | 55 |
| West Asia | −0.9 | −165 | +65 |
| China | 4.3 | 2 | 98 |

Source: Barr 1981; *Include USA, Canada, Western Europe, South Africa, Oceania, South Africa, and Eastern Europe.

phenomenally (Figure 1) and is expected to continue rising. The demand grew for soil testing, soil survey and soil classification, which became important tools of modern agriculture. The amount of fossil fuel energy used by a country became the barometer of its progress in agriculture.

This is also the period in which a great population explosion occurred, especially in developing countries. Although area expansion and yield increase both enhanced food production to meet the increased needs, there were growing signs of regional and national imbalances in food demand and supply and increasing dependence on international trade and cooperation, which has become an instrument of change in agriculture, particularly in the developing countries. It also gave rise to the revolutionary idea of international agricultural research, which became the vanguard of the new technology of high-yielding varieties. The 'green revolution' followed in the mid-1960s, with the introduction of high-yielding varieties of wheat, rice, sorghum and maize and making greater use of fertilisers, pesticides and irrigation. It benefited the developing countries dramatically and the major contribution to production began to come from increases in yield. Then came the turning point in the 1970s when consciousness began to grow about possible environmental

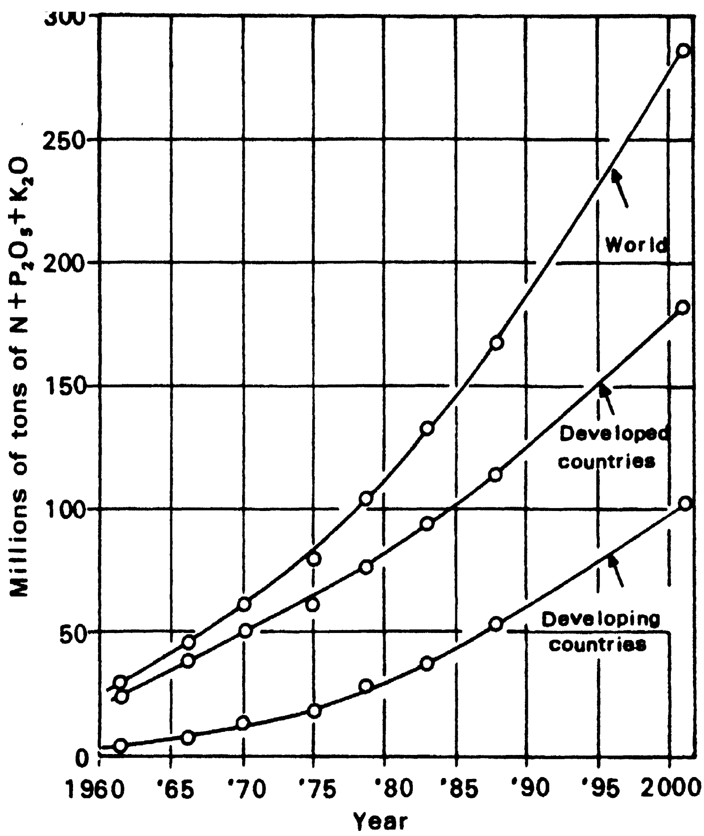


Fig. 1. World fertiliser use : projections by UNIDO

hazards arising from over-use and poor management of pesticides and fertilisers.

## Challenges to Mankind — The Theme

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At the time of the first Congress, the world was convinced that there was vast scope for increasing agricultural production through expansion of farmland by colonising new areas and migration of population from densely populated continents to those sparsely populated. It is true that even today the world is cultivating hardly 10.6% of the total land area and there remains a potential of 14.7% more arable area to be brought under cultivation, but most of this potential is in South America, Africa, North America and Oceania (Table 2).

**Table 2.** Potentially arable land and cultivated land by continent.

| Continent | Total area (mha) | Total of potentially arable land (mha) | Potentially arable land (% of total land area) | Cultivated land (mha) | Cultivated land (% of total potentially arable land) | Uncultivated but potentially arable land (% of total arable land) | Total arable land per capita (ha) |
|---|---|---|---|---|---|---|---|
| North America[a] | 2 420[b] | 626.7 | 25.9 | 273.4 | 43 | 57 | 1.84 |
| South America | 1 780 | 596.3 | 33.5 | 78.3 | 13 | 87 | 2.81 |
| Africa | 3 030 | 712.0 | 23.5 | 157.5 | 22 | 78 | 1.85 |
| Europe | 1 050 | 397.9 | 37.9 | 212.1 | 54 | 46 | 0.60 |
| Asia | 4 390 | 886.7 | 20.2 | 684.8 | 77 | 23 | 0.39 |
| Oceania (Australia and New Zealand) | 860 | 199.5 | 23.2 | 33.5 | 14 | 86 | 9.97 |
| World | 13 530 | 3 419.1 | 25.3 | 1 439.6 | 42 | 58 | 0.88 |

Source: Buringh *et al.* (1975); *a.* Includes Central America and the Caribbean Islands; *b.* This is 312 mha larger than the comparable figures in the U.S. study (PSAC 1967) and 174 mha larger than the comparable figure in FAO Production Yearbook, 1974; *c.* Based on population data in FAO Production Yearbook, 1974.

The participants in today's Congress are painfully aware of the limits to this horizontal growth and see only remote chances of bringing more areas under the plough, particularly in Asia and Europe. We realise that the available resources of land and water for agriculture are scarce. Our forest resources are disappearing fast, our costly irrigation reservoirs are silting up, and our productive farmlands are progressively going out of cultivation due to non-farm uses and soil degradation. The threats of floods and droughts are increasing and many land-degrading processes are assuming alarming proportions.

Asia, with 58% of the world's population, has only 20% of the world's arable land, 77% of which is already cultivated. In parts of south-east Asia, such as Indonesia, Thailand and Sri Lanka, serious efforts are under way, at enormous cost, to encourage the transmigration of population from relatively thickly populated to less populated areas. The scope for this kind of activity elsewhere is rather limited; also the threat to fragile ecosystems in these regions is great. Although there are over a 1000 million ha of uncropped potentially arable land in the humid tropics of south America and Africa, the majority of these soils are Oxisols and Ultisols, whose optimum use is constrained by many technological problems, compounded by socio-economic and political difficulties. Currently these areas are sparsely populated and lack the necessary infrastructure for modern agriculture. Moreover, population in Africa and south America is also increasing at frightening rates and the agricultural environment is constantly threatened by drought and floods. In any event, the ultimate moral aspect of this situation must not be taken lightly; there are vast and potentially arable unused lands in some parts of the world and dense population and starvation in other parts.

The foregoing observations and the relative contribution made by area expansion to food production in the last three decades (Table 1) clearly demonstrate that, except for Central and South America, Africa and Oceania, where expansion of area contributed significantly to additional food production and may still do so in the future, similar prospects are rather limited in other parts of the world. On the other hand, the scope for increasing productivity of lands already under cultivation with improved technology is manifold, particularly in the developing countries (Table 3). Thus, primary strategy for increasing food production in the world, particularly in Asia and Europe today, lies in improving the productivity of the land for vertical expansion, whereas in Africa and Latin America both the options still exist, as also in North America and Oceania. In the latter cases we are rapidly coming to the marginal soils. Thus, in this space age, it is of paramount importance for us to learn to manage the available soil resources efficiently to meet man's basic needs of food, fibre and shelter. Growing industrialisation, urbanisation, and civic needs are creating increasing challenges for a soil scientist of today. Hence, because of its current topical importance, we have selected 'Managing Soil Resources to Meet the Challenges to Mankind' as the theme of this Congress.

## In Retrospect

We feel greatly honoured that the 12th International Congress of Soil Science is being inaugurated by the President of India, Honourable Shri Neelam Sanjiva Reddy, who is well known for his love for soil and agriculture. He is a farmer himself and appreciates the relationship between

**Table 3.** Average and potential yields of important crops in the world.

| Source | Yield (tonnes/ha) | | |
|---|---|---|---|
| | Wheat | Rice | Maize |
| Proven potential | | | |
| (Experiment station) | 12.0 | 14.0 | 13.0 |
| Top country average yield | 5.2[a] | 6.0[b] | 5.7[c] |
| Ratio of top country average yield to developing countries average yield | 4.0 | 3.1 | 4.4 |
| Average yields by region | | | |
| North America | 2.0 | 3.7 | 4.5 |
| Europe | 3.0 | 4.8 | 3.8 |
| Asia | 1.2 | 2.4 | 1.9 |
| Africa | 1.0 | 1.8 | 1.1 |
| South America | 1.4 | 1.8 | 1.6 |
| Developed countries | 2.2 | 5.7 | 5.0 |
| Centrally planned countries | 1.7 | 3.1 | 3.0 |
| Developing countries | 1.2 | 1.9 | 1.3 |
| World average | 1.7 | 2.4 | 2.8 |

Source: Cooke (1979); *a.* Netherlands; *b.* Japan; *c.* United States.

the soil and civilisation. We are extremely grateful to him for his encouragement and valuable advice.

It is a rare coincidence that the First International Congress was inaugurated by the President of United States of America who, while addressing the Congress, stated as follows:

> The fundamental importance of the soil as a great national and international asset is at once apparent when we reflect upon the extent to which all mankind is dependent upon the soil either directly or indirectly for food, clothing and shelter. Long after our mines cease to give up their treasures of iron, coal and precious metals the soil must continue to produce the food necessary for feeding the ever-increasing population of the world. It is highly proper therefore that representatives of the nations of the earth assemble in groups such as this for the purpose of discussing methods to be employed in the study of the problems of soil conservation and land utilisaion.

We are also elated today, because the Presidents of the fifth, ninth, tenth and eleventh Congresses are present among us. Sir John Russell, President of the third Congress which met in 1935 during the period of economic depression in the world, in his presidential address stated:

> We should have the satisfaction of not only simply fostering a new aspect of our intellectual life but also by our international activities we should be able to solve these grave economic problems that have saddened so many lives during these most difficult years.

Richard-Bradfield, President of the seventh Congress which met in 1960, during the period of economic boom more than a decade after the Second World War, exhorted the soil scientists to focus attention on alleviating hunger and malnutrition—a problem of humanity transcending politics and ideologies.

Gordon Hallsworth, President of the ninth Congress, felt that there was a great imbalance in soil research, as evidenced by too many papers on soil fertility and too few on other topics. He also emphasised the necessity of bringing out a World Soil Map quickly.

Victor Kovda, the President of the tenth Congress, while addressing the Golden Jubilee celebrations of the Soil Science Society, emphasised that the problem of land resource conservation should receive the highest priority. His focus of attention was the biosphere.

My predecessor, Fred Bentley, stressed the climatic constraints to optimum utilisation of soil resources and the need for enhancing our ability to maintain and improve the soils as we use them.

I have dwelt on these excerpts to bring home the point that soil scientists from the beginning have been concerned with the impact of soil management and soils policies on human society; the problems of soil degradation, of improvement of soil productivity and amelioration of deteriorated soils have engaged the attention of soil scientists all through the decades. Yet, even today there is no world soils policy or national soils policy aiming at rational management and use of soil resources.

Lately the world has become conscious of conservation of human, animal and plant resources, but there is not enough concern about the fast-disappearing fertile topsoil which supports all animal and plant life. In her address to the FAO in 1981, Mrs. Indira Gandhi drew attention to the ravage and desecration of the earth. According to Allen (1980), 400 million tonnes of fertile soil are stripped from the land each year in Colombia; 1000 million tonnes a year from Ethiopia; 6000 million tonnes a year from India. There is a growing imbalance between forest land, grassland and cropland. Kovda (1974) observed that 5 to 7 million ha of good quality land is being lost every year from all over the world. If this rate continues unabated, the world will lose in 20 years a cultivated land area equivalent to the entire cultivated area of India today: 140-odd million ha of top fertile land which is to support the expected 1000 million people of India (or one-sixth of humanity) in the year 2000 A.D. disappearing—disappearing into thin air. Allen (1980) speculates that with the current rates of land degradation, close to one-third of the world's arable land and one-half of the world's unlogged tropical forests will disappear in 20 years. During this period the world population will increase by more than 2000 million, an increase equivalent to the entire increase in population during the time of the 11 Congresses. Is it not therefore our paramount responsibility to do something about timely global conservation and imaginative rational use of our ever-depleting soil resources?

Bentley (1978) made a strong plea for an International Soil Science Research Institute (ISSRI). The conference on alleviating soil constraints to food production on tropical soils, held at IRRI, Manila, in 1979, highlighted the need for an International Board for Soil Research and Management (IBSRM). My view is that an International Soil and Water Research Institute (ISWRI) with a network of satellite centres will be ideal for achieving all these objectives. I will revert to this aspect a little later. I earnestly believe that proper soil and water management holds the key to the problems of food, hunger and malnutrition, to the prosperity of a nation, to the quality of the environment and, ultimately, to the quality of life. Hence the theme Managing Soil Resources to meet the Challenges to Mankind is most appropriate for the 12th Congress.

## The World Food Situation, Soil Resources and Their Potential

In this Congress, Dudal from the FAO will discuss the world's soil resources and their potential and Buringh will share with you his views about the potential of these world resources. I will therefore restrict myself to a general overview. There is no doubt that world food production has not been able to keep pace with the demand in the developing countries of Asia, Africa and Latin America and future projections also show that if present trends continue, the foodgrain shortage in the coming decades will assume alarming dimensions.

The International Food Policy Research Institute (IFPRI 1977) projects that production of cereals—the major foodgrains in most developing countries—will fall short of demand by 121 to 143 million tonnes in 1990, which is three times the shortfall of 1975. This rate of deficit is likely to continue till 2000 A.D. and may touch 171 million tonnes (Crosson and Frederick 1977).

The world population was only 2 billion in 1930, reached 3 billion in 1960, 4 billion in 1975 and is expected to go beyond 6 billion by 2000. In the next 60 seconds 233 babies will be born in the world, 136 in Asia, 39 in Africa, 23 in Latin America and 35 in the rest of the world. Hundreds of millions of people in several nations still live in abject poverty and hunger. Whereas famine, hunger and malnutrition have been common and dreaded conditions since the origin of mankind, their elimination was one of the great promises of the 20th century. By the end of the century we must produce twice as much food in one year as we have done so far in the entire living history of mankind in any one year.

The core of the food deficit lies in the low-income countries with per capita income of less than US$ 300 and which contain around 70% of the world's population. Most of these areas are in Asia (Indian subcontinent), Africa and Latin America. It is not only the productivity of land that is low in these areas, but the use of productivity-increasing inputs such as high-yielding seed, fertiliser, water and energy and their efficiency of use is lamentably low.

Yet the world has in recent times often proven its capacity to feed itself: nearly 90% of the increase in grain output in the 1960s and slightly more than 70% in the 1970s came from increased yields; only in the 1950s did the major increase come from area expansion (Fig. 2).

Thus, there is a need for evolving strategies aimed at increasing intensity of cropping, enhancing productivity and improving the efficiency of agricultural inputs. The same remarks also apply to production of grasslands and forest land, which have not benefited from the results of the green revolution. This is the biggest challenge faced by soil scientists today.

At the First Congress of the International Society of Soil Science in Washington, Penck (1928) observed that the world could produce food for 16 billion people. More recently Revelle (1976) projected a carrying capacity of up to 40 billion people, while Buringh and associates (1975) estimated that under optimal conditions agriculture could increase the production to a maximum extent of 30 times the present level. For India, Sinha and Swaminathan (1979) have calculated this potential at 35 times the present level. No doubt the potential is tremendous; its realisation, however, depends on many factors, two important ones being the type of technology envisaged and the socio-economic conditions which prevail.

Thus, to critically evaluate the situation, we need to know more precisely the potential arable land resources and their production potential under different levels of agricultural inputs and technology. When we consider the assessment of the area and quality of soil resources of the world, we find that hardly one-fifth of the soils have been surveyed, and in most cases their potential for production still remains to be assessed. The highest percentage of survey coverage is found in Europe; the lowest, in Africa (Dudal 1978).

Of the 13 500 million ha total geographical area of the world, 78% is too cold, too dry, too steep, too shallow, too wet or too poor to sustain plant growth and hardly 22%, or 3270 million ha, is arable; of this only 1439 million ha is cultivated and about 1700 million ha has not yet been cultivated (Table 2). Of the arable land, 60% is of low productivity, 27% of medium productivity and only 13%, or approximately 400 million ha, of high productivity.

Figure 3 shows the distribution and main constraints of these lands in the world. How much more arable land can be cultivated depends on a number of factors—technical, socio-economic and political, which are beyond the scope of this Congress.

Of the present-day croplands which provide most of the foodgrains, four need special mention here: (i) lands under rice farming, (ii) irrigated lands of arid and semi-arid regions growing a variety of crops, (iii) lands under dry farming and rainfed farming, and (iv) lands under shifting cultivation.

**Land Under Rice Farming**

About 14% of the world's cultivated area is irrigated and a substantial

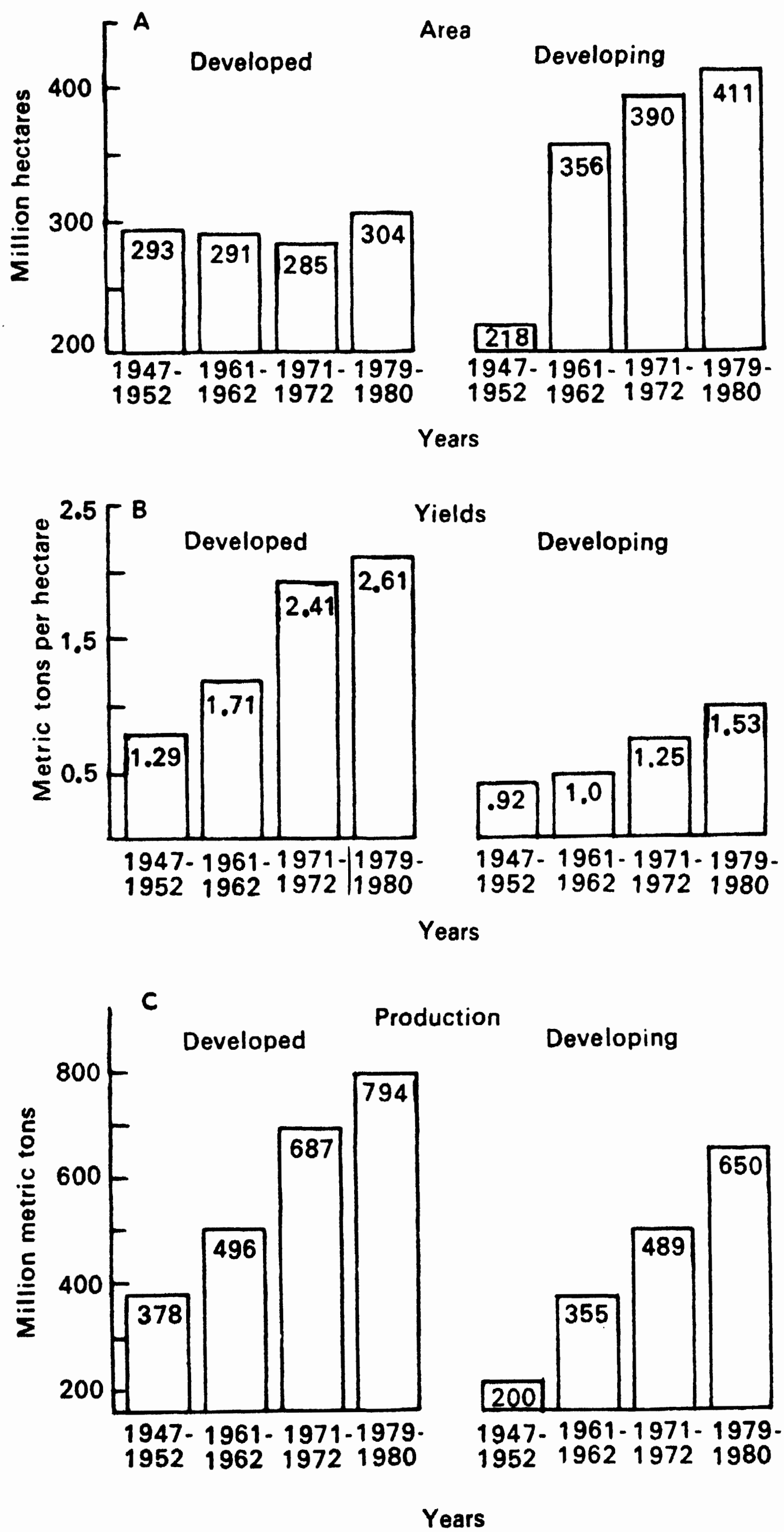


**Fig. 2. World grain in developed and developing countries. (A) Area under cultivation. (B) Yields. (C) Production.**

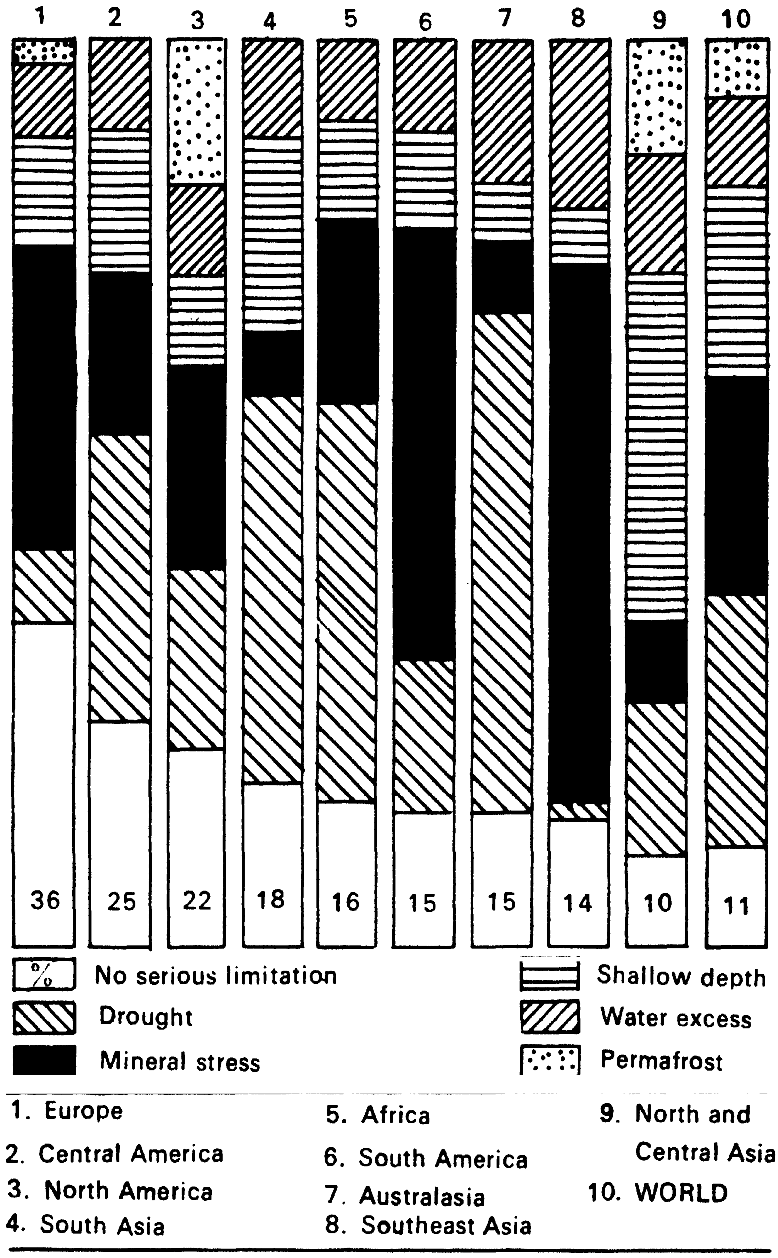


Fig. 3. Regional distribution of soils with or without limitations for agriculture. Source: Allen (1980).

portion of that is under rice (Kovda 1974). While developed countries like Japan have raised rice yields to more than 6 tonnes/ha, the world's average is less than 2 tonnes/ha. Thus increasing the productivity of rice lands in the tropics is the number one priority. In many of the rice soils, lack of drainage and lack of proper water and nutrient management are serious problems. The gulf between possible yields obtained by researchers and innovative farmers and actual national averages is very wide (Tables 3 and 4).

**Table 4.** Yields in national demonstrations on farmers' fields in India under irrigation and different managements.

| Cropping system (two crops a year) | Yield (tonnes/ha) Lowest (Poor management) | Highest (Good management) | Ratio (Highest to Lowest) |
|---|---|---|---|
| Paddy-Paddy | 3.9 | 17.1 | 4.4 |
| Paddy-Wheat | 3.7 | 14.6 | 4.0 |
| Maize-Wheat | 3.9 | 12.1 | 3.1 |

Source: ICAR 1975.

Technically there are numerous possibilities for realising this unexploited potential. The world could easily increase rice production two to three times from the lands already under cultivation.

**Irrigated Arid and Semi-Arid Lands**

Limitation of water is often considered the cause of low crop yields, but the productivity of irrigated areas in arid and semi-arid tropics of the developing countries is disappointingly low, which confirms that water alone is not enough, and many more inputs are needed to make its impact felt. The management aspect of soil and water is a critical input for realising the full potential from irrigation (Table 4). It will become even more important in the future because of increasing emphasis on irrigation in the developing countries. Thus improvement of productivity of irrigated lands, prevention of soil salinity and alkalinity and reclamation of lands degraded by salinisation assumes greater importance in these soils and the scope for increasing production is vast. In fact the world's irrigated areas could produce enough food for meeting the challenges of the future. India alone from 40 million ha of net irrigated area (with a planned increase to 77 million ha) could produce 400 million tonnes of foodgrains annually, which could feed twice the size of the present population in 2000 A.D. Therefore, the 1980s should be viewed as the decade of soil and water management.

**Land under Dry Farming and Rainfed Farming**

More than 85% of the area in the world is unirrigated and depends on rainfall only (U.S. National Academy of Sciences 1977). Some of this is in the assured rainfall areas where moisture may not be a limiting factor but soil environments may be, but in most of the areas water is a limiting factor for crop production. Besides the moisture stress, nutrient stress and soil physical environmental stress are the two other important factors affecting yields. Dry farming is the main system of farming. Due to aberrant weather and the soil-related constraints to production, the yields are low and unstable. Experimental evidence from research shows that these soils are also capable of producing many times more food with an appropriate soil and rainwater management system (Tables 5 and 6).

**Table 5.** Yields on farmers' fields under dryfarming conditions—traditional vs. improved technology.

| Crop | Traditional practice | Improved practice | Ratio |
|---|---|---|---|
| | (Tonnes/ha) | | |
| Barley | 1.28 | 2.93 | 2.3 |
| Maize | 1.22 | 2.80 | 2.3 |
| Sorghum | 0.52 | 2.52 | 4.8 |
| Wheat | 0.84 | 2.41 | 2.8 |
| Pulses | 0.55 | 1.77 | 32. |

Source: Choudhury (1979).

**Table 6.** Synergistic effect of different treatments on crop production from intercropped maize-pigeonpea in Vertisols, 1976 to 1979.

| Treatment | Crop yield (kg/ha) | |
|---|---|---|
| | Maize | Pigeonpea |
| 1. HYV only | 630 | 500 |
| 2. HYV + soil management | 960 | 640 |
| 3. HYV + Fertiliser | 2220 | 540 |
| 4. HYV + Fertiliser + soil management | 3470 | 604 |
| C.D. @ 5% | 470 | 218 |

HYV: High Yielding Variety of sorghum.

Though water is a limiting factor in these areas, a good percentage of rainwater is also wasted as runoff, which, besides being a wastage of the resource, also causes floods and erosion. Thus rainwater is the key to the success of dryland agriculture and to prevention of soil erosion in these areas (Kanwar 1980).

Agro-climatologists and soil scientists working together can provide valuable guidelines for tailoring dryland technology for making the best use of a given environment, harvesting of water and recycling it for life-saving irrigation. This type of partnership has not yet been developed fully.

Water, whether too little or too much, is a constraint to crop production. The soil scientists of temperate regions have developed considerable knowhow in the management of excess water, but the soil scientists of the tropical and sub-tropical regions have yet to develop technology suited to the twin problems of moisture deficit and excess, which often exist in the same soils, in the same season.

With the establishment of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad (India) and the International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo (Syria), the drylands of the semi-arid tropics and the arid regions have started receiving attention. The technologies developed in these institutes promise a bright future for dryland farmers.

**Lands under Shifting Cultivation**

Forty-five percent of the world's arable land is believed to be under the system of shifting cultivation and most of it is in the humid tropics. Socio-economic and political pressures are building up to transform these areas into settled agricultural systems which may open a Pandora's box of new soil management problems and accelerated erosion, for which appropriate technology based on local experience is necessary, as the model of temperate zone soil management technology has serious limitations for these soils.

A system based on minimum tillage using tree-crop interplanting and using an appropriate soil fertility management system can give higher and sustained production.

**The Future of Croplands**

Thus it can be concluded that whether these are rice lands, irrigated arid and semi-arid lands, rainfed and dry-farming lands, or shifting cultivation areas of the tropics, with the use of improved technology, the scope for increasing production from all these croplands is vast and they can meet the challenges of the future.

I have not discussed the future of grasslands, forest lands, and the lands under livestock ranching, nomadic herding or other specific uses; not that these are less important, but the considerations which apply to croplands also apply equally well to these lands and their future is also equally bright.

## Relevance of Soil Research of the Seventies

Soil scientists, irrespective of their specialisation, have been concerned with the understanding of processes and development of techniques for improving soil environments for crop production. In my opinion, they have spent more time on the former than the latter, which obviously gave the wrong impression about their intentions. Rapidly increasing demand for irrigation, fertiliser use and intensive cropping in developing countries necessitated critical examination of the concepts and techniques of soil and water management.

The oil crisis and the escalation of prices of nitrogenous fertilisers spurred the effort to improve the efficiency of these fertilisers and to find a biological means of augmenting N supply. Use of sulphur-coated urea, supergranules and nitrification inhibitors received greater attention from soil fertility specialists. Split application of fertilisers and use of legumes such as *Sesbania* and *Leucaena* for green manuring helped in effecting savings on N bills. Greater availability of soil phosphates under submerged conditions in paddy soils helped economise on phosphates. The phosphatic fertilisers when applied directly to wheat, gave significant residual effects on succeeding rice.

Mukerjee in his pioneering researches over two decades had established the importance of Al in soils (Mukerjee 1922), but it is only in recent years that its full implication has been realised. In the last decade, utilisation of acid infertile soils of the low humid tropics, using aluminium-tolerant crop varieties, has helped make the best use of such poor soils.

Micronutrient deficiency, particularly of zinc, received the greatest attention from soil chemists and soil fertility specialists all over the developing countries. Besides correcting the deficiency through the use of zinc-containing substances, the use of genotypes tolerant to deficiency has been found a promising approach. Indian soil scientists can rightly feel proud of their contribution in this area. The 1970s became a decade of micronutrient research. However, I feel that this research has grown out of proportion and at the cost of N research, which is not wise.

Studies on degradation of pesticides, absorption of heavy metals and transformation of these chemicals in soils and the development of techniques for their detoxification and absorption gained importance during this period.

The soil microbiologists took up the challenge of improving the economy of N fertilisation by exploring the possibilities for use of algae, *Azolla* and non-symbiotic N fixation. The use of mycorrhizae for releasing phosphates from unavailable forms in soils opened up new possibilities for utilising the acid soils of the low humid tropics. Organic matter chemistry, through use of sophisticated instrumentation, has unravelled the mystery of the relationship between organic matter and nutrient supplies.

The last few years have witnessed great interest in the use of organic matter and agricultural wastes for supplementing fertilisers and improving soil properties. The biogas generated from animal wastes and agricultural wastes provided a new avenue for augmenting energy supplies and manurial resources for agriculture. In this area of research also India took the lead, but China has taken up the programme on an impressive scale.

The soil physicists have successfully set up models to study the behaviour and movement of water and solutes in soils to predict the changes in soil environments in response to physical and biological factors. The wasteful and destructive effects of using heavy, energy-intensive tillage on soils for which it was not designed and the value of minimum or zero tillage, particularly for tropical soils, were demonstrated by IITA scientists in Nigeria. This has led to the development of a soil-management system for sustained production without detriment to the environment in the humid tropics of Africa.

Acceptance of the U.S. Soil Taxonomy of soil classification has grown during this period, particularly through the Benchmark Soils Project of the Universities of Hawaii and Puerto Rico, which indicates the possibilities of transfer of technology to the same soil families around the world.

The techniques for reclaiming saline sodic soils, acid sulphate soils, peat soils and aluminium-rich soils and for combating desertification have opened up numerous possibilities of bringing these problem soils into high productivity in the tropics and arid regions. The contribution of the Central Soil Salinity Research Institute, Karnal (India), for reclamation of sodic soils is well recognised. The soil scientists have demonstrated successfully what can be done in restoring these deteriorated soils to normal production.

The clay mineralogists have focused attention on soils of variable charges and developed understanding of behaviour and management problems of such soils. The relationship of clay minerals in improving efficiency of common agricultural inputs such as water, fertiliser and energy has received considerable attention.

I realise that it is next to impossible in these few minutes to give an account of the advances in knowledge and its application in agriculture and allied fields. But it would not be an exaggeration to say that soil scientists and agronomists have responded to the challenges of the times and seem to be receptive to taking greater responsibilities in the future. Expanding fertiliser technology; space-age techniques such as satellite imagery and remote sensing to assess agricultural resources; and genetic engineering are opening up new vistas in soil science research and practice as well.

## Major Soil Problems

### Soil Fertility

Nutrient deficiency is the major limiting factor for crop production in most of the world's soils and the phenomenal increases in production obtained in the last two decades are attributable to a great extent to the removal of this constraint through use of fertilisers. Whether the strategy for increasing food production is based on bringing new lands under cultivation or through intensive cropping with improved technology of already cultivated lands, both need a constant watch on nutrient supply in the soil. Both will lead to decline in soil fertility unless the input-output relationship is properly balanced.

A tribal farmer practising shifting cultivation and a modern farmer engaged in intensive farming in settled agriculture are both committing the same crime of depleting soil fertility, unless a conscious effort is made to restore to the soil what is being removed from it. In the former instance, society places some restrictions though the system is changing fast, but in the latter case the farmer is free and society pays the price. Lal and Kang (this Congress) have estimated that a newly deforested land in tropical conditions loses organic matter at the rate of 20 to 60% per annum even without ploughing. Rapid decline in soil organic matter, N, P, Zn and other nutrients is a matter of great concern and they will have to be restored to the soil and the original balance maintained if we are to produce twice as much food from the same land.

For example, in India, based on the calculations of the National Commission on Agriculture of India (1976) and my own calculation, I conclude that 130 million tonnes of foodgrains produced in 1980-81 removed 18 million tonnes of nutrients. The amount of N, P and K added through fertiliser during 1980-81 was only 5.5 million tonnes. An additional 5 million tonnes of nutrients could be considered to be replenished through organic resources (Misra 1981). This still leaves 7.5 million tonnes of nutrients which were drained off from the soil—a heavy drain on soil reserves indeed. In addition to this, India is annually losing 8.4 million tonnes of N, P and K through erosion. Other nutrients are similarly depleted. Can the soil bank remain solvent with this type of balance sheet?

A rice-wheat rotation producing 8.8 tonnes/ha per year, besides removing 663 kg of N, P and K also removes several kilogrammes of essential micronutrients as well, causing a serious drain on the nutrient reserves of the soil (Randhawa and Tandon 1982). Thus it is not surprising that micronutrient deficiency is becoming so severe in the intensively cropped areas. Fifteen years ago in the state of Punjab, zinc deficiency became prominent; today, manganese and iron deficiencies are also evident (Kanwar 1981a). In India as a whole, 47% of the soils have become deficient in Zn, 5% in Mn, 11% in iron, and greater incidence of micronutrient deficiency is reported from states which have more irrigated area and more intensive cropping and harvest higher yields. Ludhiana district (Punjab), which records the highest yields of many crops, also reports the highest deficiencies of micronutrients. Intensive cropping and higher yields are only possible through balanced fertiliser use, to maintain high productivity (Kanwar 1981b).

Long-term experiments in temperate regions and in India indicate that with balanced manuring under intensive cropping soil fertility can be built up rather than depleted, but experience in the humid and sub-humid tropics is rather limited. At IITA, more than 10 years' experience in continuous cropping indicates serious problems of soil deterioration. Thus it is reasonable to assume that in the humid tropics, tree farming may be better than crop farming, but more long-term research is needed as the ecosystems of the rainy humid tropics are more unstable.

IFDC-UNIDO (IFDC 1979) estimates show that the world consumption of fertilisers will rise to 264 million tonnes of N, P and K in 2000 A.D. from 89 million tonnes in 1976—nearly three times the present level. Most of this fertiliser will be nitrogen—140 million tonnes. The developing countries are likely to consume 92 million tonnes of N, P and K as against 172 million tonnes consumed by the developed countries. This brings out clearly the great disparity between the developed and developing world, both in total fertiliser consumption and in ratio of nutrients. It also confirms that in the world's strategy for increasing food production, fertiliser is a key factor and soil scientists must pay greater attention to its management.

Although N deficiency is most serious, the P and K position is equally disturbing. When we look at the global picture, we can calculate that 1500-odd million tonnes of cereals are annually removing 30 million tonnes of P. Assuming 15 million tonnes is being returned to the soil in various forms, this leaves a negative balance of 15 million tonnes of P annually. The mineral phosphate deposits are non-renewable resources. Thus there is a greater need for recycling the phosphates and also for releasing them from unavailable orms through appropriate biological and chemical means. This aspect is ttracting more attention in the management of the acid infertile aluminium-ich soils of Latin America.

Large quantities of nutrients are being exported from the producing areas o the consuming areas. The countries exporting agricultural commodities and orest and animal products must bear in mind the drain on plant nutrients and ake appropriate steps to encourage farmers to invest in soil amendments, ertilisers and manures to restore nutrient balances in the soil. Unless every hipload of bananas going out of a country also brings back into the country proportionate amount of K, there will be great deficiency of K for the crop.

*Low Efficiency of Applied Fertiliser.* Even where fertilisers are applied, heir use may not always be efficient; thus another problem which we have to ake note of is the low efficiency of applied fertiliser in developing countries, articularly in the tropics. The major fertiliser used in most of the developing orld is nitrogenous fertiliser and its efficiency of use is hardly one-half of hat in the developed countries, particularly in rice. Where N applied to rice in he developing countries of south-east Asia is giving only about 30% fficiency, in some developed countries and also experimentally, more than )% efficiency is commonly obtained. Thus increasing the efficiency of N from ) to 50% in rice cultivation in India, which is at present using 1.4 million onnes of N, would amount to a saving of 0.56 million tonnes of N, or ontributing to 9.3 million tonnes of additional foodgrains. Realising that N is he most expensive input and its manufacture requires a large amount of nergy, the agricultural world should give top priority to improving the fficiency of this fertiliser and to supplementing it through biological N xation and organic manures. Thus in the decades ahead the greatest nportance should be attached to these two aspects of research. No doubt onsiderable progress has been made in this area but nitrogen still remains an nigma (Greenland and Watanabe, this Congress).

While fertiliser technologists have to modify the fertiliser products to suit he soil, the soil scientists should learn to modify the environments to improve rtiliser-use efficiency. Controlled nutrient release to suit different soil and ant environments is a high priority. Additional work is needed on urease nd possible nitrification inhibitors and on ways to prevent ammonia olatilisation, denitrification and leaching losses. The effective utilisation of sidual soil moisture on low-fertility Vertisols during the post-rainy season esents a challenge to soil fertility experts because of positional unavailability fertiliser N.

**rganic Wastes and Plant Residues in Soil Management**

In many countries inadequate attention is being paid to organic wastes nd recycling of crop residues. It is shocking to see about 5 million tonnes of e straw being burnt in the fields from October to December every year in unjab state (India), which has been a leader in the green revolution. Besides being a loss of valuable nutrients and organic matter for soil improvement, this burning is causing a serious problem of atmospheric pollution and health hazards. Allen (1980) reports that 500 million tonnes of dung and crop wastes—badly needed for improving the soils—are being burnt by the rural people in the developing countries.

**Soil Erosion and Degradation**

There are various estimates of soil degradation. According to Kovda (1977) the loss of available land in the world is 5 to 7 million ha per year, which may probably rise to 10 million ha per year by the end of this century.

Systematic estimates of the extent of degradation are being made by FAO/UNEP throughout the world but so far data are available only for African states north of the Sahara and the Near East.

About 45% of the world's exploitable soils (another estimate puts this at 30% of the total usable land) are under shifting cultivation in Africa, Latin America, Oceania and south-east Asia. Today, due to increased pressure of poulation, these areas are even more threatened. The continued destruction of the tropical forests is of great concern. It has been estimated that tropical rainforests are being burnt at the rate of 11 million ha per year—about 20 ha per minute—and at this rate all the tropical rainforests will have disappeared within 85 years (Allen 1980). Deforestation makes the soils more vulnerable to erosion.

The arid and semi-arid areas are suffering from increasing soil erosion and reduced productivity due to over-stocking and over-grazing and the end result is complete desertification. It is estimated that more than one-third of arable lands are exposed to such a threat in the world.

In India, Tejwani (this Congress) has estimated that 33% of forest lands, 86% of cultivable waste lands, 95% of pastures and grazing lands, 74% of fallow lands and 58% of cultivated farm lands are subject to severe erosion.

The Indian National Commission on Agriculture (1976) reported that out of the 328 million ha of total land area in the country, 150 million ha are subjected to serious erosion by water and wind, of which 69 million ha were at a critical stage of deterioration due to erosion. John Pesek (1980) in his presidential address to the American Society of Agronomy stated that the USA is losing 1.2 million ha (3 million acres) annually due to erosion. These estimates appear frightening, but erosion can be minimised, though not completely eliminated. One way of minimising the soil erosion from agricultural lands is through raising productivity and keeping them under crop cover for longer periods. In India, 28 million ha of Vertisols if brought to a higher level of production with improved technology and kept under crop cover during the monsoon season will mean reduction in soil loss of about 140 million tonnes of soil annually. Similar examples can be cited from elsewhere. Thus improving productivity through modern agriculture is one sure way of reducing soil erosion.

*Increased Flood Hazards.* Floods are considered national disasters all :r the world but their increasing intensity and extent is due chiefly to kless deforestation and poor management of soils in the catchment areas of river systems. Increasing soil degradation and loss of organic cover ıance the fury and extent of floods. In India the flood-prone area has reased from 25 million ha in 1950 to 40 million ha in 1980 (National mmission on Floods 1980); the experience in many other developing ıntries is similar. While soil conservationists have to develop techniques of :elerating the generation of biomass and reducing runoff from the tersheds, governments must consider whether they should spend funds on ɔd-protection measures in the plains or on reducing the threat in the tersheds, through soil conservation and land improvement methods. One y of ensuring vegetative cover is by increasing the productivity of forest ds, grasslands, and croplands with modern agriculture. In many of these as, silvi-pastoral activity, instead of arable farming, will be more effective considerably reducing flood hazards and meeting the economic needs of ›ple.

*Increased Siltation of Reservoirs.* Another serious problem caused by ter erosion is the increased rate of siltation of water reservoirs and dams. ;ides reducing water storage and capacity to produce energy, it has ›rtened the lives of the irrigation dams constructed at great cost. Indian ›erience shows that the rate of siltation in many dams has become four to ht times the designed capacity, which reduces the payoff drastically. ıether it is the Aswan dam in Egypt or the Bhakra dam in India, the story the same.

The developing countries are vying with one another to create more gation potential by investing in prestigious irrigation projects. The World nk and other agencies are advancing huge sums of moneys for such ıstruction, but the payoff will depend wholly on proper management in the tershed areas and in the lands to be irrigated. It is high time that soil :ntists began to play their rightful role in these projects, which should be ;arded not only as feats of engineering but in their totality as a means of ıserving and efficiently using the precious water resource.

*Increased Desertification.* Escalation of human and animal population ension of cropping to lands which should have been used only for pastoral ming, over-grazing, deforestation and neglect of appropriate soil ıservation and management practices have accelerated wind erosion and ;ertification. The United Nations Conference on Desertification in 1977 has :used attention on this subject and the symposium on this subject will bring t the role of soil scientists in combating it.

*Increased Urbanisation.* According to World Bank estimates (1979), by : year 2000, half of the world's population will be living in urban areas. banisation and the requirements of land for civic uses are increasing at an rming rate and the situation is equally serious in both the developing and the developed world. Buringh (this Congress) estimates that by the year 2000, nearly 200 million ha of potentially productive cropland in the world will be completely lost to non-agricultural uses. According to Allen (1980) fertile land is fast disappearing under concrete and tarmac: together the USA and Canada submerge 4800 $km^2$ (480000 ha) of prime cropland under buildings, roads, reservoirs, and other non-farm uses. In India also the runaway rate of urbanisation is staggering; topsoil is removed for making bricks; unplanned excavation and horizontal expansion are leading to greater erosion hazards, water stagnation and salinity, blemishing the whole landscape. Swaminathan (1977) has observed that for housing the urban population of India, 3000 million tonnes of topsoil are in danger of being excavated. In view of these threats of national disasters and rapid loss of good agricultural land, a world soils policy for conservation and rational use of land resources is essential. Such a policy could ensure the use of marginal land for non-farm uses instead of annexing prime agricultural land. I hope the symposium on world soils policy in this Congress will evolve an agenda for action for the world community and national governments.

**Problem Soils, their Reclamation and Management**

Many kinds of problem soils exist in the world, each of them hampering agriculture in one way or another (Dudal 1978). Red tropical soils, sandy soils and shallow soils pose problems of soil fertility and soil conservation and other soils pose problems of water management. In this category are included the Vertisols, peat soils, acid sulphate soils, saline sodic soils, Planosols and fine-textured alluvial soils. Beck and associates (1980) estimated that the area under these soils was about 1.5 billion ha. Soil scientists all over the world have been developing technologies for their reclamation and management and have achieved some success but there are still numerous technological problems such as subsidence, compaction, salinisation, erosion and acidification; there are in addition socio-economic problems also which affect the utilisation of these soils.

*Saline and Alkali Soils.* Irrigation is considered a critical input for removing moisture stress and stabilising agricultural production in the world. But irrigation is not an unmixed blessing. Very large areas of good agricultural land are going out of cultivation in the dry regions of the world due to poor water management which results in waterlogging, salinisation and alkalinisation of soil, reducing productivity. United Nations (1977) estimates show that about 120 000 ha of irrigated land are annually lost to production in this way. The significance of irrigation in the history of world civilisation and in supplying the growing population with foodstuffs and raw materials can hardly be overemphasised. It is not by chance that ancient systems of irrigation and drainage developed in valleys and deltas of rivers such as the Nile, the Tigris, Euphrates, Ganges, Indus, Mekong, Yangtze and Amu Darya. Today between 230 and 240 million ha of land are under irrigation in

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Waterlogging and salinity in canal-irrigated areas have reached very serious dimensions globally. Kovda (1974) estimated that secondary salinisation and alkalinisation have turned about 20 to 25 million ha of formerly productive lands into barren saline wastes by irrigation without drainage. The most obvious examples of this type of land degradation are in Iraq, Iran, India, Pakistan, Egypt, Transcaucasian USSR and Argentina. The total area of saline and alkali soils of the world is estimated to be about 323 million ha (Beck *et al.* 1980).

In India, 7 million ha of potentially productive lands have become barren because of salinity and alkalinity; an additional 6 million ha of lands are affected by waterlogging. The menace of salinity and alkalinity is growing fast and according to Vohra (1980) it is not unreasonable to believe that 10 million ha of the 40 million ha of net irrigated areas are affected by salinity and waterlogging. The threat of this kind of soil degradation is particularly serious in the Vertisol and related soils of India which are coming under new irrigation projects. The nature and amount of clay and the lack of surface and underground drainage make these soils more vulnerable to the sodium hazard. In the Chambal Irrigation Project—a typical Vertisol—25% of the land became affected by salinity and alkalinity within 10 years of the introduction of irrigation. The increase of the problem in Vertisols of Karnataka and Andhra Pradesh and the Tawa Project of Madhya Pradesh (India) points to the dangers associated with irrigation in this group of soils in the semi-arid tropics and arid regions of the world. Salinity is more serious in the arid regions and the formation of alkali soil in the semi-arid regions; both develop in the wake of irrigation. Thus, on the one hand, prevention of salinity and alkalinity and, on the other, reclamation of such deteriorated soils and restoration of their productivity assumes the greatest significance in the future.

Fortunately, the principles of management of these soils are now well established, although application of these to different conditions needs to be tested. A technique based on the use of fertiliser manures, gypsum and high-yielding varieies of rice and wheat has been found very effective on the alkali soils of the Indo-Gangetic plains. The experience of the Central Soil Salinity Research Institute, Karnal (India), shows that 2.5 million ha of such deteriorated soils can be made to produce 7 to 8 tonnes/ha of rice and wheat annually from the third year of reclamation. Agro-techniques have been developed for raising fuel wood and timber wood on such soils in the Indo-

1. Another estimate puts this at 500 million ha.

Gangetic plains and enabling economic utilisation of these lands without irrigation. We believe there are numerous possibilities of dealing with such situations and modern technology offers many alternatives.

**Soil-Related Constraints of Tropical Soils**

Though there is considerable scope for area expansion in Latin America and Africa for producing more food, reclamation costs and the creation of an infrastructure to facilitate an economic level of production are possible constraints. Scarcity of labour and traction power is also a serious constraint. In many potentially arable lands, water is a limiting factor and high costs often make irrigation schemes unattractive. The main plank of any strategy for increasing production in the developing world, especially in Asia, is through economic maximisation of productivity per unit area per unit time. In this strategy all three aspects, increasing productivity, restoring productivity and preventing deterioration of productivity, are important. In tropical Africa and Latin America rational extension of agriculture to new areas and increasing yield and sustained productivity is the answer.

Thus for optimising production per unit of land under cultivation, removing of soil constraints to production and using modern technology based on judicious use of inputs assumes highest priority in all tropical regions. In this context, let me recall a statement by N.C. Brady (IRRI 1980) when he opened the workshop on priorities for alleviating soil-related constraints to food production in the tropics; he observed that soil-related factors are among the most significant constraints on crop production in the developing countries. Ignorance of improved technology and lack of inputs have constrained the farmers from improving crop performance in areas with poor soils. In the soils of the humid tropics, the severest limitation is the deficiency of phosphate, accentuated by high phosphate-fixing capacity, high acidity, toxicity of aluminium and manganese and deficiency of calcium, magnesium, zinc and boron.

Sanchez and Cochrane (1980) stated that out of 1043 million ha of acid infertile soils of Latin America over 90% have N and P deficiency; 70% have K deficiency, 62% zinc deficiency. Besides, 72% of them show Al and Mn toxicity and 56% have shallow depth. On the other hand, in high base status soils like Alfisols and Vertisols, more than 50% have erosion, moisture stress and N and P deficiency limiting crop production. In many situations, liming does not seem to be a practicable proposition because of non-availability of lime at the sites of use and the high cost. Moreover, the experience with liming in temperate region soils is not transferable to tropical soils, particularly to the low-activity clays. Recourse has been made to use of rock phosphate, silicates and other phosphates of low availability.

In the tropical rainforests of Africa, after land clearance, soil erosion becomes more severe due to quick oxidation of the organic matter and disappearance of the organic mulch cover from the soil. The microbiologists and environmentalists fear that this will not only reduce fertility but also contribute to increasing atmospheric temperature and $CO_2$ concentration; the climatologists fear that this will cause major changes in the climate of tropics. I believe IITA's experience of minimum tillage is highly useful for proper management of soils of such humid tropics particularly for Oxic Paleustalfs.

In the semi-arid tropics nearly 56% of soils are represented by Alfisols, Vertisols and sandy soils of the Inceptisol type (Kanwar 1981c). I consider it sufficient here to make a passing reference to Vertisols, which form the subject of a special symposium. Low workability, susceptibility to erosion, low infiltration, low fertility, poor drainage and occasional moisture stress are the main constraints to crop production in Vertisols.

Erratic responses to and low efficiency of urea observed under rainfed copping in Vertisols seriously impede extensive use of fertilisers in these soils. In Alfisols, nutrient stress, moisture stress and physical impedance to crop stand establishment are serious constraints, but with proper management techniques these soils also produce many times more and suffer less erosion. However, more research is needed to develop suitable land treatment for these soils.

Concern about the loss and deleterious effects of nitrogenous fertilisers has led, in recent years, to greater interest in research on biological nitrogen-fixation studies in the tropics. The symposium on non-symbiotic nitrogen fixation in this Congress will indicate the scope of this subject and future research trends.

Weeds and pests are serious constraints to crop production in the tropics and the use of pesticides and herbicides for successfully raising crops looks promising; however, there is inadequate information on retention and biodegradation of these chemicals under tropical conditions. The experience in temperate region soils is not necessarily applicable in this situation.

The importance of soil mineralogy to food production and economic development has not received adequate attention in tropical regions. We are now beginning to understand the significance of variable charges and surface phenomena to fertiliser use and efficiency. A conference on soils of variable charges held in New Zealand last year was a step forward in this direction.

I have stressed the importance of soil constraints to crop production in the tropics because there is a tremendous need for increased productivity in these regions of rapid population increase. In the plenary session of this Congress, Swindale will give special attention to the problems and potentials of soils of the semi-arid tropics, Osman to soils of arid regions and Brady to the problems of tropical rice soils.

In the past, the philosophy has been to modify the soil environment to suit the plants. Because of the technological and economic difficulties of applying this technique in many areas, a new philosophy of tailoring the plant, through genetic engineering, to suit the environment has become necessary.

The aluminium toxicity in highly acid soils of the tropics, in newly reclaimed areas of the Amazon basin in Brazil and elsewhere is being tackled through sorghum, rice, maize and wheat genotypes less susceptible to Al toxicity. Likewise, for making the best use of soils affected by salinity and alkalinity or a specific micronutrient deficiency, the crop species or genotypes tolerant to or capable of giving higher yields under these environments are attracting the attention of scientists.

Biological nitrogen fixation through symbiotic and non-symbiotic means and phosphate mobilisation through use of mycorrhizae seem to hold potential for utilising soils with limited N and P availability. It appears that in the coming decades genetic engineering to adapt the plant to a specific environment will produce results of practical value. Thus the soil scientist's role in identifying and categorising the environments, working together with the geneticist and the plant breeder to develop genotypes suited to each environment, is becoming important. The only danger in this approach is that by rigorous selection we may end up with plant types which may exhaust a particular nutrient or ultimately make it uneconomical to profitably grow crops in such soils. The international symposium on plant adaptation to mineral stress in problem soils and to other soil constraints affecting crop production held at Cornell (1976) discussed many aspects of this approach. I consider it as an important approach for international collaboration.

The Technical Advisory Committee to the Consultative Group on International Agricultural Research emphasised research on several aspects of soil science research which warrant international support (TAC 1979). These are:

- improving and maintaining with low inputs the potential of infertile tropical soils;
- understanding principles and methods of soil conservation, particularly in semi-arid and arid zone soils;
- improving water management technology for major irrigation projects;
- correlation of natural soil inventories to overcome the site specificity of soil research; and
- use of bench-mark sites and need for soil-plant-water studies on them.

## Strategy for Meeting the Challenges of the Future

The challenges to soil scientists in the decades ahead can be grouped as under:

- Improving the agricultural productivity of the land that is already under cultivation and developing rational systems of management for new lands for farming, recreation and urbanisation.
- Improving the efficiency of agricultural inputs such as water, fertiliser, energy and pesticides, which are necessary for increasing productivity.

- Preventing soil degradation caused by man's negligence and ignorance.
- Reducing soil erosion, desertification, salinisation and land degradation by ensuring efficient soil and water management systems.
- Restoring and improving productivity and utility of degraded lands to meet the immediate and future needs of society for food, fibre, shelter and recreation.
- Monitoring changes in the productivity of land and developing a system of warning, treatment and care.

These challenges are common throughout the world; only their intensity and order of priority varies. Acid rain, open cut mines and pollution are major problems in industrialised countries. These countries maintain high productivity of agricultural land through heavy use of fertilisers, pesticides and energy; hence they are concerned with avoiding the harmful effects of these inputs and with the recycling of agricultural and urban wastes for useful purposes. They are equally concerned with the improvement of land degraded by heavy metals, radioactive isotopes and industrial effluents and with the quick and safe disposal of urban wastes.

In many developing countries, the major emphasis is on improving agricultural productivity of land to produce more and more food on less and less land, but the problem of improving the environment and of preventing harmful effects of industry is also becoming gradually more important. Because of the high cost of manufactured inputs such as fertilisers, pesticides and machinery, the problem of improving efficiency of inputs assumes even greater significance in these countries. Water is costly and is getting polluted. Loss of N from fertilisers applied to the soil not only means economic loss, but also poses health hazards. Increasing the efficiency of water use—whether rain or irrigation water—is the key to improving productivity of land and preventing its degradation. In many developing countries labour is not a limiting factor but land is, and improving productivity per unit land per unit time is the goal. Thus, labour-intensive, energy-economising technology aimed at optimising production from land and other agricultural inputs is the ideal system for such situations. On the other hand, even some developing and all developed countries have a scarcity of labour and traction power, hence for such situations the priority is different.

The increasing costs and shortage of energy make it imperative to decrease the use of non-renewable energy sources in agricultural systems. Most of the energy in agriculture is used to manufacture nitrogenous fertilisers, pump water, and mechanise farm equipment. Any improvement in the economy of these will help economise on energy, while sustaining productivity in many ecosystems, particularly in tropical areas.

Thus, the soil scientists of today face many more diverse demands on their expertise than the participants of the first Congress faced. All soil scientists, whether they be soil physicists, chemists, biologists, or pedologists, must fully understand input-output relationships in agriculture as well as environmental concerns. I need hardly emphasise that I have used the term agriculture in a very broad sense, including forestry and animal husbandry as well. I find very few soil scientists taking an interest in management of forest lands and grasslands. Unless we learn to manage them well we cannot combat natural disasters and meet the challenges of the future. The solution to many of our soil problems lies there.

A Japanese soil scientist in the Osaka region may give high priority to problems of toxification by heavy metals; a Chinese scientist to reclamation of peat soil for rice production; an Indian scientist to soil, water and land management in the Vertisols of peninsular India or to zinc deficiency in the saline-alkali soils of the Indo-Gangetic plains; an African soil scientist to management of Alfisols in the sub-humid tropics and combating desertification in the Sahel region; a Brazilian soil scientist to making the aluminium-rich acid infertile cerrado soil suitable for producing maize or beans. The priorities may vary, but the challenges are the same; the practices may be different, but the principles and tools of soil science are the same.

## Looking Ahead

It is presumptuous on my part to comment on the future needs and trends of soil research because of the complexity of the problems and the fast development of technology which makes all projections about the future difficult. I am sure the panels of experts on different subjects will make a critical evaluation of the past and future when they dicuss the key question, 'Whither Soil Research?'

Soil physicists are aware that we are critically short of understanding the behaviour of the soil under field conditions, particularly in the tropics. We should go to the field rather than spending all our time packing soil in the lab. I could not agree more with Nielsen when he says that modellers and simulators should withdraw somewhat from the computer console and experimentalists should occasionally step into the computer centre. The soil physicist should help change the trend towards over-mechanised and energy-wasteful agriculture and improve efficiency of water, fertiliser, tillage and drainage. Modellers should be able to predict the behaviour of soil, plant and input interaction and to monitor input-output relationships. There are very few soil physicists working on the soil and its relationship to nutrient availability, crop stand, sustained agricultural production or erosion. We have not made use of advances in science and technology or worked together with agricultural climatologists in predicting the interaction between weather, soil and plant better.

The energy crisis has revived interest in supplementing chemical fertilisers with biofertilisers and phosphate release from unavailable forms to improve soil productivity. Thus, the pendulum of research in the future should swing to soil chemists and microbiologists working together rather than separately. More sophisticated techniques should help in resolving many controversies and changing old dogmas. Let us recognise that legumes do require energy for fixing N and also nutrients like phosphate, molybdenum, boron, etc. How much progress we will make in the next decade is difficult to predict.

In the field of soil fertility, the necessity of intensive research on controlled nutrient release and improved efficiency of nitrogenous fertilisers for drylands and wetlands needs highest priority. The changes in nutrient supply and uptake by crops with receding moisture or increasing moisture in the soil profile under rainfed conditions of the tropics and with or without irrigation in the semi-arid tropics, need special emphasis. Despite the large number of scientific papers on soil fertility, which has been the trend all through the previous Congresses as well, and was specially commented upon by E.G. Hallsworth, President of the 9th Congress, we still do not have a satisfactory method of predicting fertiliser needs and availability, particularly the N needs of a crop, much less of a cropping system in the humid tropics, semi-arid tropics and arid lands. (I am not sure if such information is available even on temperate region soils.) The quantification of N utilisation under different management systems needs attention.

Soil fertility specialists may think of working together with plant geneticists in adapting plant to soil environment and with fertiliser technologists in modifying the fertiliser products to suit the environment. They should not remain confined to one approach of modifying the chemical soil environment by liming or gypsum application. The problem o toxification from heavy metals is becoming serious in industrialised countries and soil scientists should recognise and tackle it.

The pedologists have come a long way in developing a soil classification system but they still need more information about tropical soils. The best tribute to eminent pedologists from Dokuchaev to Guy Smith and their contribution to the development of soil taxonomy and classification would be for the pedologists to agree on one uniform system of soil classification. It seems appropriate that the chairman of Commission V has recommended naming the panel discussion on whither pedology the Guy Smith Symposium.

Before leaving this subject, I would like to emphasise that the pedologists have looked at the pedon too long; let them now use their knowledge for the transfer of technology of soil management. How long will we continue arguing about how the soil was formed? We were not there when it was formed, but we want to see in our life time the knowledge of soil survey and classification being effectively used for managing soil resources to meet the challenges to mankind.

The soil technologists may feel proud of their technology for increasing production from all soils, including deteriorated soils, but the attainable potential and the cost-benefit relationship are more important now. We should be aware of the limitations of high-energy technology and develop alternative approaches compatible with the socio-economic conditions of the situation.

The clay mineralogists may rightly lament the inadequacy of research in clay mineralogy but they should be concerned about the lack of utilisation of already available knowledge of the subject for soil management technology. I am sure the panelists of all the commissions have a number of suggestions for researchers for meeting the challenge to soil scientists in the decades to come. However, unless the education programmes prepare the scientists to make use of advances in knowledge of the related sciences and of instrumentation, including remote-sensing technology, we may not be able to progress fast. We should not forget that laboratory studies are only a means to an end, not the end itself, and the ultimate test of our research is in the field. We envy the space research scientists for the precision and accuracy with which they have landed man on the moon or put the satellite into orbit. Can we not aim, in the use of soil science for crop production or environmental improvement, for a similar precision? I believe we can.

## Concluding Comments

I see many eminent soil scientists present at this International Congress today who were also present at the UN Conference on Environment in 1972 which I had the privilege to attend. This is also the 10th anniversary of this UN Conference. It is a good occasion for us to remind ourselves that soil is the base of all we produce and reproduce and it needs attention. *Save the soil and serve humanity* should be our motto. Let us, in this Congress, take note of the FAO's adoption of the World Soil Charter and lead the way in formulating a world soils policy.

I consider soil and water as one system, interacting on plant and man. A number of international agricultural research institutes have been set up in the world for crops and animal research but it has been overlooked that soil research needs special emphasis. Unless the soil and water are managed properly, the potential of the high-yielding seeds and the strategy of increasing food production through intensive use of technology in agriculture may not produce the desired results. Embryo culture and genetic engineering may offer many new genotypes but you need soil for producing them on a lare scale. The Consultative Group of International Agricultural Research has proposals for ISSRI, an International Soil Science Research Institute, IBSRM, an International Board for Soil Research and Management and an International Water Management Centre. These could be combined together into one International Institute which may be called International Soil and Water Research Institute (ISWRI), with a network of centres in different regions. I am happy to mention that India has already taken a lead in including the establishment of National Soil Research Institute in the country's sixth Five Year Plan. Similar action is needed on an international basis.

We find ourselves at the crossroads where the energy crisis, the rising costs of mechanised farming and land reclamation and the increasing land degradation prevent us from expanding agriculture to new areas. The good agricultural lands are rapidly slipping out of our hands into non-farm uses. We also find ourselves faced with this dilemma: for increasing productivity of the land we need water, fertilisers, energy and pesticides, yet their high prices, low efficiency of use and environmental hazards—real and imaginary—place a serious limitation on their use. Hence our major task is to improve their efficiency while avoiding their harmful effects on the environment.

We cannot ignore the threat to the environment from various forms of erosion, land degradation, including toxification with heavy metals, poisonous gases, effluents and other pollutants. Let us not overlook the fact that poverty, hunger and malnutrition are an even greater threat to the environment and the only way of alleviating them is through increase in productivity of land and water.

The soil scientists must recognise soil and society as a single system in which man can be either a positive or a negative factor, depending upon how he acts. Today's world is conscious of the energy crisis and has a slogan 'Save the Oil' but we seldom hear the slogan 'Save the Soil'.

With today's technology we can certainly modify soils to man's advantage. We can predict the changes and improvements if we know our soil well. We could computerise irrigation schedules, fertiliser needs and likely response of soils to management. I consider the 1980s a decade of integrated soil management systems or better soil-water-plant management systems in which all scientists, planners and farmers work together to save the soil, improve its health and make it produce to its potential capacity, which is very high.

Whether there are disasters like floods or droughts, food or water famines, energy crises or health hazards, poor soil management is the cause. We have the capacity to improve the situation but we need the will to do it and a national and world soils policy to accomplish it.

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