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REPORT ON THE SOILS CONSTRAINTS CONFERENCE

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A conference entitled "Priorities for Alleviating Soil-Related Constraints to Food Production in the Tropics" was held at IRRI with sponsorship from USAID and the Federal Ministry of Economic Cooperation of West Germany (GTZ) in order to bring together leading tropical soil scientists from developing country national institutions, international centers, and developed country universities and agencies to answer two questions:

1) What are the main soil constraints in the tropics and mechanisms to alleviate them?
2) What mechanisms can be developed to remove these constraints in the different ecological regions of the world?

Cornell University and IRRI organized the conference under the leadership of Drs. H. G. Zandstra and A. Van Wambeke. They were assisted by a Steering Committee appointed by Dr. Brady on August 22, 1978 composed of A. Van Wambeke and H. G. Zandstra (Co-Chairman), L. D. Swindale, D. J. Greenland, P. A. Sanchez, G. Uehara, J. J. Nicholaides, III, and W. M. Johnson, which met in Edmonton at the ISSS meetings and developed the first list of the program and participants.

A total of 70 scientists from 31 countries participated in the actual conference. Their names are listed in Appendix 1. This includes LDC national institution representatives from: Philippines, Malaysia, Sri Lanka, Thailand, People's Republic of China, Bangladesh, India, Kenya, Sudan, Cameroon, Nigeria, Ghana, Sierra Leone, Trinidad, Guyana, Brazil and Peru. The international centers represented were: IRRI, ICRISAT, IITA, ICARDA and CIAT. The developed countries represented were: Australia, Japan, West Germany, France, Netherlands, United Kingdom, Canada and the United States. In addition, there were representatives from FAO, the International Soil Science Society, the Inter African Bureau of Soils, and the International Fertilizer Development Center.

A total of 21 invited papers were presented and distributed in draft form. The list appears in Appendix 2. The papers are being edited by M. Drosdoff of Cornell and W. Rockwood of IRRI. The proceedings will be published in book form early next year.

This report describes the authors' perceptions of 1) the highlights of formal meetings, 2) priority constraints and research areas and 3) the organization of a worldwide coordinating center. The official conclusions of the Conference are expected to be included in the final publication.

## HIGHLIGHTS OF FORMAL PRESENTATIONS AND DISCUSSIONS

### General

In his opening address, N. C. Brady stated that soil problems are now recognized by leaders in international agricultural development as increasingly relevant. The first production breakthroughs came with improved varieties, partic-

ularly rice and wheat, but now it is widely acknowledged that even though the genetic potential is necessary to improve yields, the environment becomes an increasingly important constraint, particularly the soil environment.

The plant breeding breakthroughs are good, but not good enough; the physical and chemical soil environment has tremendous impact on crop productivity. Scientists and politicians alike are now realizing that increased efforts in removing soil constraints are needed.

In our view, this situation is analogous to human development, where both genetics and the environment determine the outcome of human personality. The major thrust on plant improvement should be balanced with environmental constraints, which could be alleviated (e.g., by breeding crops for tolerance to soil acidity) or removed (e.g., by liming).

L. D. Swindale stated that the world can potentially feed 10 times the present population if its entire soil resources were fully utilized. During the past 20 years, 2/3 of the increases in world food production has been due to yield per hectare increases, mostly in developed countries. Only 40% of the world's potentially arable land is being utilized. Therefore, there is a great gap to cover by soils research both in terms of opening new lands and in increasing production. In addition to production, there are other major issues: equity, (the limited resource farmers must produce more food), conservation and ecology.

There is a need for an international effort in stimulating and coordinated soils-related research. Dr. Swindale reviewed earlier proposals and stated that this is an idea whose time has come. He proposed a new body, a coordinating center based on the benchmark soils concept and suggested that it be initially

headquartered at FAO or IRRI. In the discussion that followed, the idea of basing the center on the Benchmark project was dispelled quickly. Throughout this discussion, it became clear that the participants of this conference were unanimously in favor of developing an international soils coordinating center.

R. Dudal's presentation emphasized the need to coordinate and conduct soils research along major agroecological zones, such as udic rainforests, ustic acid soil savannas, semi-arid tropics, wetlands, etc. The present definition of the ustic soil moisture regime (wet/dry seasons) is too broad; it should be subdivided in two, the dividing line being a 6-month dry season. There were many statements of support for this idea.

FAO estimates that if per capita food production is to remain at present levels, food production must increase by 60% within the next 20 years. Increasing yields on lands already in use is not sufficient to accomplish this. FAO estimates that an additional 200 million hectares must be incorporated into agriculture in order to accomplish this. On the question of yield increases vs. opening new lands, Dudal concludes that the need for opening new lands and keeping them productive is without question.

Dudal pleaded to pay more attention to surface layers in soils research. This part of the soil profile, largely ignored in most soil classification systems is the key one for plant growth.

The present status of Soil Taxonomy was described by W. M. Johnson. Three new points came out: 1) The Fertility Capability Classification System is considered an important interpretation of Soil Taxonomy, 2) The Soil Conservation Servise is open for even drastic changes in Soil Taxonomy such as new taxa for

paddy soils, modification of moisture and temperature regimes for the tropics, and changing chemical criteria for more modern ones, such as aluminum saturation.

On paddy soils, the concensus is that a sub-order of Inceptisols for paddy soils is probably needed. Frank Moormann proposed the definition of the "anthraquic" soil moisture regime, described by surface gley development on well-drained subsoils.

Ecological Region Reviews

Four papers described soil constraints in relation to major farming systems in tropical Africa, humid tropical Asia, tropical America and the semi-arid tropi

Humid Tropical Africa. Moormann and Greenland's paper emphasized that rainfed traditional farming systems and transitional food crop systems are dominant in Africa. Most traditional systems are closely related to the environment and maintain productivity at a low level without serious soil deterioration. The major soil constraints are: 1) Low nutrient levels, 2) rapid erosion and 3) secondary (i.e., management-related) soil acidity. Increasing yields within the context of traditional and transitional farming systems is preferable to attempts to introduce land management systems from other regions which fail to give sufficient attention to site-specific soil and climatic properties.

Large-scale, capital intensive food crop farming systems in lowland humid Africa have largely failed, while tree-crop based systems, either by plantations or small holders, have generally succeeded due to a better ecological adaptation. Zero tillage cultivation systems appear very promising, particularly if recycling of basic cations is included by using deep rooted trees or other species.

Emphasis should be placed on the management of soils with low activity clays (Ultisols, oxic Alfisols, Oxisols). There is a major potential of "opening new lands" in the wetlands of tropical Africa, now largely under-utilized because of fear of river blindness. About 10% of humid tropical Africa could be developed for paddy rice cultivation.

Humid Tropical Asia. Dent's paper divided the continuum of farming systems into eight ones, three of which are based on wetland rice (irrigated, rainfed and deep water), four are dryland systems (annual crops, perennial crops, crop/pastures and crop/timber), and one is shifting cultivation. Eight soil constraints were identified: Water deficit, water excess, mechanical impedance to land preparation, shallow depth, low soil fertility, soil acidity, salinity and erodibility. The constraints were related to the farming systems in an 8 x 8 matrix table.

The priorities for the wetland rice systems should be geared towards realizing the full potential of new rice production technology including: 1) extension of irrigation facilities to provide water control for high yielding varieties, 2) breeding to develop high yielding varieties tolerant to drought, pest, disease and soil stresses, and 3) in-depth fertilizer research in benchmark sites.

About 72% of the area have excluding soil constraints for the three rice systems. Given the technological advances in rice, more attention should be given to the dryland systems, including: 1) Alternatives to mechanized land clearing, 2) erosion protection following clearing, 3) fertility research on benchmark cropping systems sites, 4) development of cultivars tolerant to soil

acidity, 5) crop protection and 6) intercropping systems. The main dryland soils of humid tropical Asia are Ultisols, many of which are shallow and/or hilly.

Many of these constraints have been already researched in Ultisols of South America. Extrapolation of the technology developed there and on-site validation in Asia should perhaps be the first step. Differences in fertilizer use and availability between the two regions should be considered.

In regard to the last system, shifting cultivation, Dent recommends its replacement in populated areas, rather than improvements within the system. Dudal emphasized that although shifting cultivation is efficient in terms of energy conversion, converting labor calories into food calories guarantees perennial poverty.

Several participants disagreed. Greenland pointed out that improved shifting cultivation systems support human population densities of 300-500 persons/$km^2$ in Ultisols of Eastern Nigeria. H. Y. Chan from Malaysia mentioned that the soil requirements for perennial crop production are different for those of annual crops.

Tropical America. Sanchez and Cochrane divided tropical America in two major regions: High base status soils with generally dense populations, covering 30% of the area, and acid infertile soil regions with low population densities covering the remaining 70%. Ten farming systems were described for the first region, considering differences in soil moisture and temperature regimes, and five farming systems were identified for the acid infertile soil

region. Twenty-seven soil constraints were identified and their areal extent estimated based on the FAO world soil map and soil taxonomy interpretations. The main soil constraints in the high base status soil region are drought and erosion. In the acid infertile soil region, the main constraints are chemical.

The main research priorities for removing the major soil constraints were identified as: 1) Develop stable, productive and energy efficient farming systems for the acid, infertile soil regions of tropical America, both in savanna and forested ecosystems, 2) develop practices to keep the soils covered to prevent erosion in high base status soils, 3) develop a data base of land resources, quantitative criteria for each soil constraint, including the classification of crops and cultivars according to their tolerance to adverse soil factors, and 4) strengthen soil fertility evaluation services.

Semi-Arid Tropics. Kampen and Burford's paper indicates that development in the semi-arid tropics must be geared towards two objectives: 1) Arrest deterioration of the resource base and 2) increase production to match population growth.

Unreliability of sufficient water for assured crop growth is without a doubt the main constraint. Unreliability of rainfall can be defined as a degree of risk. For example, at Hyderabad, India there is more than a 70% probability of a continuous wet period sufficient for crop stand establishment, and maximum grain crop yields can reach 5 to 7 tons/ha. Nearby in Sholapur there is only

50% probability of such a continuously wet period; in other words, crop establishment would fail every other year. The average yields in Sholapur are 1 to 3 tons/ha.

Vertisols are the most important soils in the semi-arid tropics of India, but not in semi-arid zones of Africa, Southeast Asia and Latin America where Alfisols and Entisols are the most extensive soils.

Alleviation of the main soil-related constraints appears feasible in deep Vertisols of India by implementing ICRISAT's "watershed-based" farming systems. This involves a combination of improved land, water and crop management practices, varieties and intercropping systems at medium-input levels.

The main constraints in India's Alfisols are low moisture-holding capacity and shallow depth. Plants can survive two to three weeks without rain in Alfisols of Hyderabad, while in adjacent Vertisols they can survive five to six weeks. Both figures are high when compared with the even lower water-holding capacity of Cerrado Oxisols, where corn wilts after one week without rain.

Kampen and Burford consider priority soil research areas 1) low soil fertility (primarily N, P and Zn), 2) improve water and nutrient utilization of sandy, easily erodible soils (Entisols, Inceptisols) that dominate the semi-arid tropics, 3) increase N fixation and 4) breed varieties for improved efficiency at low soil fertility levels.

Chemical Soil Constraints

Nine papers dealt directly with soil acidity, salinity, nitrogen, phosphorus, potassium, sulfur and micronutrients as specific constraints on a tropics wide level. The highlights follow.

Soil acidity. Aluminum toxicity in "dryland" soils is an important constraint in 40% of tropical Asia, 20% of tropical Africa and 40% of tropical America. Kamprath listed the priorities for alleviating it as: 1) Use KCl-extractable Al as the most practical criterion for determining rates of lime applications. 2) Determine through research the most appropriate factor to convert exchangeable Al to tons/ha of lime for specific farming systems. 3) Determine critical levels of % Al saturation for main plant species and cultivars and classify them in tolerance categories. 4) Increase the number of long-term liming trials to assess length of residual effect, the development of secondary acidity and any downward movement of Ca and Mg. 5) Breed and select cultivars tolerant to Al toxicity, both to reduce lime requirements and increase root development in acid subsoils, which would improve water utilization. 6) Promote nutrient recycling of basic cations where lime is unavailable or very expensive, including tree crops and/or fallow systems. 7) Determine critical levels of Mn toxicity and the extent of this constraint. 8) Tackle nutritional imbalances in long-term trials. 9) Develop models to predict when secondary acidity will develop according to soil properties, N fertilization, climate, etc. Secondary acidity is not only important in the humid tropics, but also in the semi-arid tropics with very poorly buffered soils.

Acid wetland soils pose unique constraints, stated Van Breemen. Deep ombrogenous Histosols and Sulfaquepts should not be considered for rice development, because the possibilities of success are slim. Where no other options

exist or where commitments have already been made, preference should be given to Sulfaquepts that have a nearby supply of high quality irrigation water. The main priorities are: 1) Develop physical-chemical criteria to separate those low potential soils from those that have higher potential (e.g., Aquults, shallow Histosols, Sulfic Tropaquepts, Sulfic Haplaquepts and others). 2) Quantify soil factors important for rice, taro and sago palm production in acid wetland soils both for short and long-term productivity. 3) Determine the effects of temporary drainage on oxidation-reduction reactions in acid wetland soils. 4) Characterize better the acid wetland soil sites where experiments are conducted.

Saline soils. A considerable acreage of saline soils occur in the humid tropics. Bandopadhya and Ponnamperuma's paper gave the research priorities as: 1) Screen and select varieties for tolerance to saline soil conditions of differing types of saline soils. 2) Separate high conductivity soils where the soil solution is dominated by $Na^{+}$ from those dominated by $Al^{+++}$ and $Fe^{++}$. 3) Develop criteria for determining which saline soils have a reasonable potential for paddy rice and other crops, and eliminate those that do not. 4) Develop critical levels for salinity tolerance, at the appropriate growth stages, for important tropical crops, pastures and their main cultivars.

Conventional methods for reclamation of saline and sodic soils in arid areas need to be validated at the site-specific level.

Nitrogen. In his first paper, Bouldin mentioned that the basic concepts of N management are well-known, but what is needed is their practical applica-

tion to specific systems in the tropics. An exception to this statement is N dynamics and management in intercropping systems. Nitrogen in crop residues is probably a larger source of N to crops than N fertilizers. Residue management is crucial in long-term experiments and farming systems involving continuous cultivation. Site-specific field programs is the main priority, emphasizing the following components: 1) Recycling of N, 2) correctly timing and applying the proper amount of N fertilizer and 3) improving the utilization of organic sources of N.

In an impromptu report on biological N fixation, Peter Dart mentioned that is no longer necessary to amend the soil to fit the requirements of *Rhizobia*. It is now possible to select *Rhizobia* strains tolerant to soil acidity, salinity, flooding (for pulses in rotation with rice) and even high soil N contents. The main limiting factor is the crop's yield potential. Nitrogen fixation in intercropping systems is an important research area. Priority research areas mentioned in the App-Bouldin-Watanabe paper are: 1) Select *Rhizobium* strains to match soils and local cultivars. 2) Review the needs for P and Mo fertilization. 3) Develop superior yielding varieties of grain legumes. 4) Develop legume-based forage production systems for those soils marginal for food grain production. 5) Develop *mycorrhiza* inoculants for legumes. 6) Develop improved methodology for estimating non-symbiotic N fixation, and 7) select variant forms of *azolla* and blue green algae suited to local rice soils.

Phosphorus. Without a doubt, P is one of the most extensive constraints and a very expensive one to correct in soils with high fixation capacity, such as

Oxisols, Andepts, clayay Ultisols and oxic Alfisols. No clear recommendations were made in the formal presentation. In our opinion, the main priorities are: 1) Determine the internal and external critical levels of P for main soil-crop situations. 2) Breed cultivars for tolerance to low available P levels. 3) Intensify the evaluation of direct applications of rock phosphates, particularly in acid soils and 4) Determine the long-term residual effect of P applications in specific farming systems.

Sulfur. Blair's paper emphasized that sulfur deficiencies have been reported throughout the tropics, although the amount of research is rather limited. The increasing use of lime and phosphate fertilizers will decrease S retention in surface soils and may result in less S available for crop growth. Fertilizers manufactured at present are devoid or low in S and deficiencies will increase unless S is incorporated into the fertilizers. Sulfur fertilization dramatically increases the methionine content of grain in areas where S is deficient.

Priorities for sulfur research are: 1) Development of chemical methods to estimate sulfur availability. 2) Coordinated investigations of the effect of sulfur fertilization on crop yield and quality. 3) Selection of varieties which are efficient in the use of sulfur. 4) Study sulfur reactions in dryland and wetland soils as to efficiency of fertilizer sulfur sources, leaching and residual values and long-term effects. 5) Methods of incorporating sulfur into fertilizers that will be used in the tropics.

Potassium. Kemmler stated that coarse-textured soils and soils with predominantly kaolinitic clays generally have low reserves of potassium while soils with 2:1 clays generally have good reserves of K. There are indications that the available K levels of certain soils used for rice in Southeast Asia are low. In areas where plant residues are removed and not returned to the soil in the form of compost or manure the need for fertilizer K will be increased. Long-term field experiments are needed to assess the K needs in tropical areas and to provide data for soil test correlations. Although many soils in the tropics are low in K, the use of fertilizer K should be based on soil tests rather than following blanket recommendations for K.

Additional information is needed on critical levels of K for soils containing primarily kaolinitic clays and those containing 2:1 type clays. Attention needs to be given to the effect of K fertilization on Mg uptake and requirement by various crops.

Micronutrients. Although micronutrient studies have been conducted in many areas of the tropics, Lopes deplored the lack of adequate soil characterization which seriously limits the extrapolation of the results. Future studies must include adequate soil characterization and classification of the soils to permit extrapolation. In the acid savannas of South America, zinc deficiency is a severe limitation to crop production. Ultisols in the Amazon jungle of Peru were deficient in B, Cu, and Mo. Volcanic ash soils, particularly the older ones, were deficient in Mo. Overliming of Entisols, Oxisols and Ultisols

in Africa have resulted in deficiencies of Mn and Zn. On the other hand, Mn toxicity has been observed in the acid Entisols. Boron deficiencies are extensive in Africa on hydromorphic soils and Alfisols. Molybdenum deficiency has been a problem in the acid sandy soils in Africa. Zinc deficiency in lowland rice has been observed in the calcareous soils in Asia. Iron deficiencies of paddy rice have been found in the calcareous soils where low organic matter contents limit soil reduction.

Soil characterization for soil classification purposes should also include micronutrient analyses. Increased attention must be given to field studies on response of crops to micronutrients and identification of soils deficient in micronutrients. The efficiency of various forms of micronutrients need to be evaluated for various farming systems and the residual effects. Determination of critical levels for both soil tests and tissue analyses for micronutrients are needed.

Soil Physical Properties

Drought. Hsiao's paper pointed out that due to soil limitations such as the presence of high impedance layers, soil acidity and associated problems, water stress in crops is not confined to semi-arid areas. Essentially humid areas with a marked seasonal rainfall distribution could suffer from drought effects for several months of any year and irrigation would be essential for all-year crop production.

Research priorities on drought-related research include: 1) Better meteorological data of field sites. 2) Determine how much water is held at different

potentials in the main soils of the tropics. 3) Incorporate water-related parameters into the soil classification system. 4) Determine potential rooting depth of species and cultivars at both high and low levels of input use. 5) Breed and select cultivars for drought resistance.

Mechanical impedance to land preparation and seedling emergence. Nicou and Charreau presented an excellent review of soil compaction as an important constraint, and related their findings to soil taxonomy terminology.

Tillage in tropical soils must be viewed in the broadest sense and should not be automatically interpreted to mean the use of mechanical implements; biological tillage may be very appropriate where erosion hazard and the cropping system warrants it. There are two opposite and contradictory dogma on this issue in Africa: Zero tillage, especially for the humid tropics and deep tillage for the semi-arid tropics. The point is not to generalize like that but to develop the best practice for each local situation. The danger of compaction, surface crusting and mechanical impedance for seedling emergence is simply related to topsoil physical properties. Kaolinitic soils that have less than 18% clay, and probably less than 5% organic matter, have a great danger for compaction. This could be incorporated as an additional modifier in the Fertility Capability Soil Classification System.

In general, tillage is needed in these sandy Alfisols as well as in montmorillonitic soils. Tillage should be avoided in soils with gravelly topsoil layers and where organic matter contents are low. In other words, if there is

mechanical impedance tillage must be used. Another priority is to reduce the use of very powerful machinery to break compacted soils as ways of economizing energy.

Mechanical impedance to root growth. Taylor identified several major knowledge gaps about this constraint in the tropics. They are: 1) The ease with which tropical soils develop high strength layers when subjected to heavy farm equipment. 2) Comprehensive soil maps for extrapolation purposes. 3) Determine the ability of plants to penetrate high strength layers that exclude roots of most crops. 4) Interactions between mechanical impedance and other soil factors that affect root growth.

Erosion. Lal reviewed the impressive amount of existing data on soil erosion losses, particularly in Africa, but the depressing fact that very little is being done about preventing it. He expressed the need to become quantitative about erosion losses and proposed the use of the "Y50" parameter, i.e., tons per hectare of soil loss required to decrease yields by 50 percent. Priority should be given not only to preventing erosion but also to reclaim eroded land economically.

Research needs are both basic and applied. The basic information currently used in the tropics is that developed in the temperate region. Major differences in climate and soil suggest that it would be mere coincidence if the empirical relationships developed in one climatic region can be directly transferred to the other. Specific research needs are: 1) Wind erosion--an essentially ne-

glected area in the tropics. 2) Gully erosion: Develop inexpensive and effective control methods. 3) Rainfall parameters affecting erosivity such as drop size, distribution, kinetic energy and momentum of tropical storms, should be determined to quantify the erosivity of tropical rains. 4) Basic and applied aspects of erodibility of key soils. 5) Soil management practices to prevent erosion, such as no tillage. 6) Methods of bulldozer land clearing that do less physical damage to the soil. 7) Integrated watershed management.

Extrapolation of Soil Research Results

Buol and Nicholaides' paper emphasized the need to translate soil information in understandable terms to four main audiences: 1) Other research scientists, 2) politicians and development officials, 3) extension workers and 4) farmers. In the last category farmers with access to capital are interested in maximizing profit per unit of purchased input, while resource poor farmers are interested in minimizing risks.

Soil properties considered for taxonomic purposes are not necessarily relevant for soil fertility purposes. Dudal has stated that the upper 20 cm which soil classifiers are discarding because it is so variable is the key zone for soil management and crop production. Data of Sopher and McCracken showed that 70% of the crop yield variability in 441 field trials was explained by a combination of all topsoil properties, while the subsoil properties explained markedly less.

The Fertility Capability Classification System (FCC) as proposed by Buol, Sanchez, Cate, and Granger, and which builds on soil classification information

is presented as one means to overcome the primary constraint to soil fertility evaluation and extrapolation of research results. The FCC consists of three levels: Type - the texture of the surface 20 cm; Substrata type - the texture of the subsoil if there is a change within 50 cm; Condition Modifiers - specific properties noted if a specific range of condition is encountered.

When the FCC was used to group soils from McCollum and Valverde's potato fertilization trials in the Sierra of Peru, the 73 sites were grouped into five categories. Economic analysis of the response curves showed that fertilizer recommendations based on a combination of the FCC and soil test analyses gave the highest gross returns to fertilizer of any system tested.

The FCC when properly used by building on Soil Taxonomy information and combined with soil testing is given as one means to enable soil researchers to help the farmer, no matter how small or remotely located, to reduce his risk and increase his probability of producing economical crop yields.

## PRIORITIES BY ECOLOGICAL REGIONS

Participants were divided into three groups: Humid tropics (both udic and ustic), tropical wetlands and semi-arid tropics, with the charge to bring together the information into coherent research priorities by ecological regions. The verbal reports are transcribed below. It should be noted that no ranking of priorities is included in these reports.

Humid Tropics

Develop productive, low cost, energy efficient, ecologically sound components of soil management systems for humid tropical rainforests and ustic savanna regions that are to be opened for cultivation to supply the additional 200 million hectare requirement by the year 2000. The main components of the systems are:

1) Solve the soil acidity constraint by liming to neutralize the required amount of exchangeable aluminum and/or develop cultivars tolerant to high levels of Al saturation. Estimate residual effects, downward movement of Ca and Mg, development of secondary acidity, evaluate Mn toxicity and avoid imbalances between Ca, Mg and K. Recycle bases from the subsoil by using deep rooted crops, if possible.
2) Intensify long-term phosphorus fertilization studies with particular attention to P fixation. Select systematically cultivars that are more efficient in using low levels of available soil phosphorus.
3) Apply nitrogen management practices at the field level with emphasis on crop residues, leaching and research for better understanding nitrogen management in intercropped systems.
4) Resolve the sulfur deficiency constraint associated with higher yields and high analyses fertilizers.
5) Characterize micronutrient limitations better.
6) Intensify studies on periodic drought stress, particularly as related to subsoil aluminum toxicity.

7) Develop crop management practices to maximize the use of available soil water.

8) Pay more attention to topsoil properties, both physical and chemical.

9) Erosion is a major constraint in ustic moisture regimes. More basic knowledge about the components of soil erosion is needed, but above all practices that keep the soil covered at all times.

10) Develop safer land clearing methods.

11) Develop methods for reclaiming already eroded soils.

12) Develop mixed cropping systems of perennials with annuals, including pastures.

13) Use a land evaluation-extrapolation approach composed of:

    a) Land resource inventories, including Soil Taxonomy.

    b) Fertility Capability Soil Classification System.

    c) Soil fertility evaluation services.

Interpretations should be flexible and adapted to local conditions.

Tropical Wetlands

The definition of tropical wetlands is "land that is water saturated to a shallow depth either naturally or artificially having either an aquic or an anthraquic soil moisture regime." The research priorities are as follows:

1) Complete taxonomic and soil classification data of experimental fields. This is notoriously weak in rice research where very little soil characterization has been made.

2) Develop chemical and physical criteria to separate unsuitable soils from suitable ones. When other options are available deep, ombrogenous Histosols and Sulfaquepts should be eliminated in favor of other acid wetland soils that have greater potential such as sulfic groups of Inceptisols and Entisols, shallow Histosols and Aquualts.
3) Management strategies for acid sulfate soils should be tested and refined
4) Effects of temporary drainage must be studied, in terms of the physical and chemical dynamics.
5) Determine the areal extent on different kinds of saline soils, select cultivars tolerant to different degrees of electrical conductivity and develop criteria to determine which soils have high pay-off potentials.
6) Conduct coordinated multilocation long-term field research networks on the effective continuous flooding on phosphorus transformation and mechanisms for improving phosphorus efficiency in rice culture.
7) Identify areas with sulfur deficiency and increase the understanding of sulfur dynamics in flooded soils.
8) Delineate areas deficient in zinc.
9) Nitrogen research has to be more integrated, including residue management and manures.
10) Apply the FCC system, adding a modifier for the degree and duration of flooding.
11) Take into account soil variability rather than soil similarities.

Semi-Arid Tropics

This group listed the following priorities:

1) Research in water deficiency and brief seasonal excesses, N fixation and N fertilization are the main concerns.
2) Characterize the constraints better, including the present status of erosion hazard, the development of secondary salinity and secondary acidity.
3) Develop methods to relate better soil survey to land utilization.
4) Soil testing, FCC and its implication to semi-arid tropics needs to be strengthened and should be targeted to the smaller farms.
5) Research should be done on a farming system basis.
6) Importance of crusting, seeding emergence and impedance is recognized.
7) Attenuate the effects of development of secondary salinity in irrigated land and secondary acidity in soils with low activity clays.
8) Intensify research on phosphorus deficiency, residual effects of P fertilizers and the development of phosphorus efficient cultivars, as needed.
9) Sulfur deficiencies are important; need to develop soil tests.
10) Potassium long-term studies are needed.
11) Zinc, boron, molybdenum deficiencies are the main micronutrients; need critical levels of soil test and tissue analysis.
12) Conduct benchmark-type field experiments on nitrogen efficiency, particularly intercropped legumes.

13) Assess erodibility.

14) Develop low input strategies.

This section was very aptly closed by Dr. Dudal who emphasized that although long-term studies are needed, let's have a sense of urgency in our research. Long-term studies require about 10 years to get the data, but we have to feed 2 billion additional people within the next 20 years. A sense of urgency in soils research is needed, and if it is used as a criterion, the above-mentioned priorities for the ecological regions can be boiled down to more coherent ones.

## DEVELOPMENT OF AN INTERNATIONAL BODY FOR COORDINATING SOILS RESEARCH

The entire last day of the conference was devoted to this issue. In the morning the participants split into three groups who discussed the role of 1) international centers, 2) developed country institutions, and 3) national developing country institutions. In the afternoon, Chairman Leslie Swindale summarized the three reports in the following manner:

1) There is a unanimous agreement that a coordinated body is needed and is indeed recommended by this conference.
2) The objectives of this body would be:
   a) Catalysis and communications, that is, not being an executor of research, but serving a function similar to the International Board of Plant Genetic Resources in further increasing food production by alleviating soil constraints, as soils are the basic resource of world agriculture.
   b) To mobilize resources and direct attention to soils research in the tropics.

3) The mechanisms for achieving these objectives would be:

a) A small central secretariat to do the promotion, and communication operations.

b) A documentation center, including abstract services, translation of key publications and their distribution. The documentation center would be analogous to the commodity-oriented documentation centers presently operating at the International Centers.

c) Data banks both on soil properties per se as well as the results of the experiments, identification of technology ready to transfer, development and coordination of methodologies to facilitate international communication (not to standardize methodologies worldwide but to provide a suitable international forum).

d) Encouragement of training, development of conferences and workshops.

4) Organization: The International Board on Soil Management Research or some such title (no title was proposed) would have:

a) A small central secretariat with few operational responsibilities.

b) A board of trustees of an international nature to set policies.

c) A possible arrangement was proposed by Dr. Brady and appears in Appendix 3.

5) Follow-up: The participants authorized the organizers of this conference (Cornell and IRRI) to circulate the results and solicit the reaction of relevant national and international organizations. A steering committee of ten members

would be appointed, with representatives of international centers, developed country institutions and one representative of each major geographical region of the developing world. Chairman Swindale closed the meeting saying that the organizers of this conference would select the steering committee. After some feelings expressed on the matter, Cornell and IRRI decided to ask each participant for nominations of membership in the steering committee. This has been done.

# APPENDIX 1

## PARTICIPANTS IN THE SOILS CONSTRAINTS CONFERENCE

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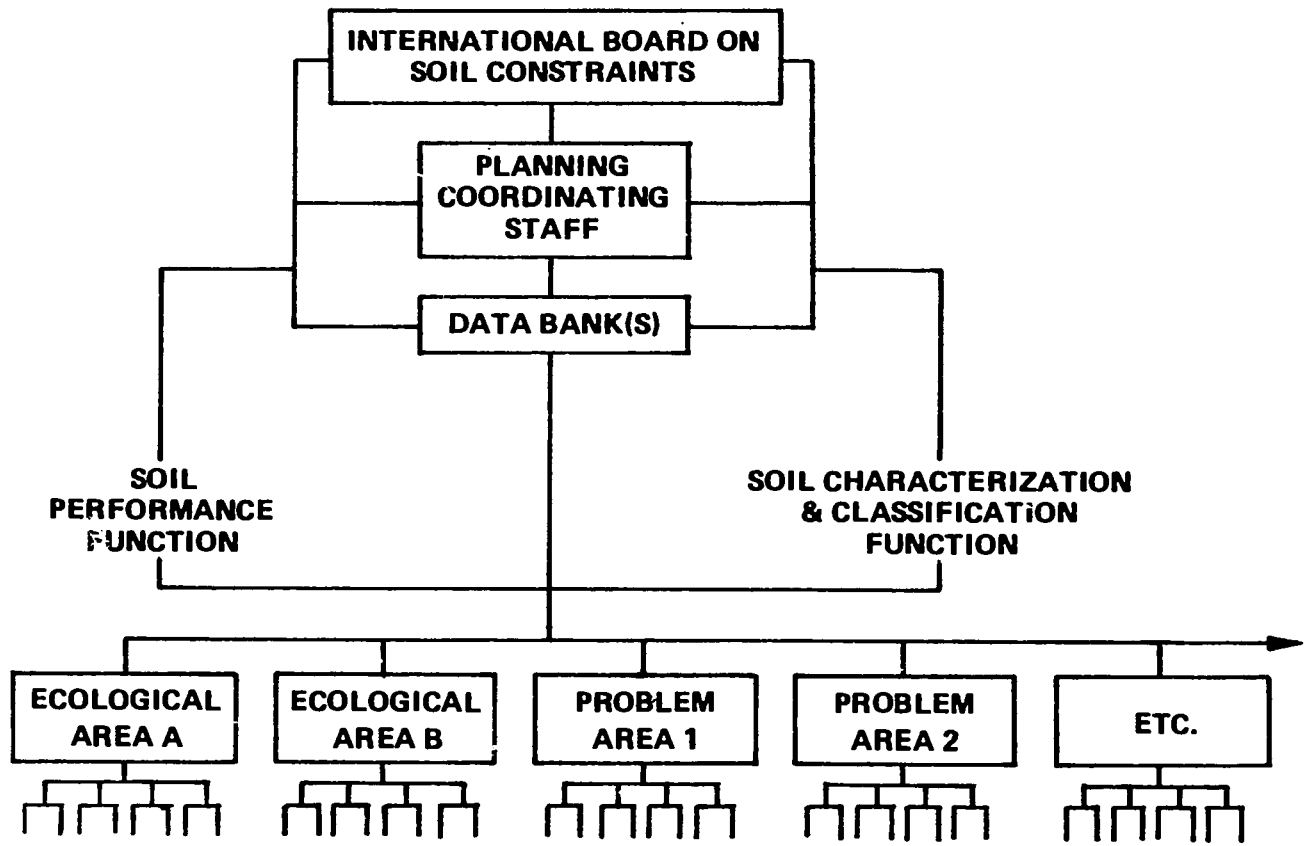
# APPENDIX 2

## PAPERS PRESENTED AT SOILS CONSTRAINTS CONFERENCE

1. L. D. Swindale (ICRISAT): Toward an internationally-coordinated program for research on soil factors constraining food production in the tropics.
2. R. Dudal (FAO): Soil-related constraints to agricultural development in the tropics.
3. W. M. Johnson (USDA): Soil-related constraints, soil qualities and soil taxonomy: a terminology for exchange of scientific information.
4. F. R. Moormann (Utrecht) and D. J. Greenland (IRRI): Major production systems and soil-related qualitied in humid tropical Africa.
5. F. J. Dent (FAO, Indonesia): Major production systems and soil-related qualities in humid tropical Asia.
6. P. A. Sanchez and T. T. Cochrane (CIAT): Soil constraints in relation to major farming systems of tropical America.
7. J. Kampen and J. R. Burford (ICRISAT): Production systems, soil-related restraints, and potentials in semi-arid tropical regions of Asia, Africa and Latin America.
8. E. J. Kamprath (NCSU): Soil acidity in well-drained soils of the tropics as a constraint to food production.
9. N. van Breemen (Wageningen): Acidity of wetland soils and histosols of the tropics as a constraint to food production.
10. F. N. Ponnamperuma (IRRI) and A. K. Bandyopadhya (India): Soil salinity as a constraint in food production in the humid tropics.

11. B. Dabin (ORSTOM): Phosphorus deficiency in tropical soils and its prejudicial effects on agricultural output.
12. G. J. Blair (Australia), C. P. Mamaril (IRRI) and M. Ismunadji (Indonesia): Sulphur deficiency in soils of the tropics as a constraint to food production.
13. G. Kemmler (Germany): Potassium deficiency in soils of the tropics as a constraint to food production.
14. A. S. Lopes (Brazil): Micronutrients in soils of the tropics as a constraint to food production.
15. D. R. Bouldin (Cornell), W. S. Reid (Cornell and P. J. Stangel (IFDC): Nitrogen as a constraint to non-legume food crop production.
16. A. A. App, D. R. Bouldin (Cornell) and I. Watanabe (IRRI): Constraints to biological N fixation in the tropics.
17. T. C. Hsiao, J. C. O'Toole and V. S. Tomar (IRRI): Water stress as a constraint to crop production in the tropics.
18. R. Nicou (IRAT) and C. Charreau (ICRISAT): Mechanical impedance to land preparation as a constraint to food production in the tropics.
19. H. M. Taylor (USDA): Mechanical impedance to root growth.
20. R. Lal (IITA): Erosion as a constraint to food production in the tropics.
21. S. W. Buol and J. J. Nicholaides (NCSU): Constraints to soil fertility evaluation and extrapolation of research results.

Appendix 3. A possible arrangement of the International Board on Soil Management Research as viewed by Dr. N. C. Brady.