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# Rainy Tropical Climates: Physical Potential, Present and Improved Farming Systems

S.W. Buol and
P.A. Sanchez

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S. W. BUOL and P. A. SANCHEZ[2]

Rainy tropical climates: physical potential, present and improved farming systems.[1] Professor and Associate Professor, respectively, Soil Science Department, North Carolina State University, Raleigh, N.C. 27607, U.S.A.

No single presentation can adequately portray the rainy tropics in sufficient detail or totality. Perhaps the words of Henry Walter Bates (1910), relating his impressions while on the Amazon River, can best convey a setting of the region:

> "It is never either spring, summer, or autumn, but each day is a combination of all three. With the day and nights always of equal length, the atmospheric disturbances of each day neutralizing themselves before each succeeding morn; with the sun in its course proceeding midway across the sky, and the daily temperature the same within two or three degrees throughout the year - how grand in its perfect equilibrium and simplicity is the march of nature under the equator!"

Perhaps of greater influence on the temperate zone inhabitant are the less gentle descriptions of the area such as:

> "Even the nights give little relief from the oppressive heat. Yet, to the poorly clad and none too vigorous natives, who are sensitive to even the slightest drop in temperature, the humid night air may appear even chilly." (Trewartha 1937).

In our effort to summarize the present conditions and estimate the potential production of the Rainy Tropical Climatic Area defined by Trewartha (1968), we have attempted to study as many factual reports and respected opinions as possible. However, in an area so socially, politically, economically and physically diverse, many equally competent studies and opinions are contradictory, each tempered by the limited experience of the author or authors. It is certain that these same limitations inflict themselves on our effort.

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[1] Paper No. 5471 of the Journal Series, North Carolina Agricultural Experiment Station, Raleigh, N. C. 27607, U.S.A.

[2] Presently Soil Scientist and Coordinator, Beef Production Program, Centro Internacional de Agricultura Tropical, Cali, Colombia.

## PHYSICAL POTENTIALS

The physical or environmental potential for net primary production in tropical rain forests is as high as any environment on earth (Table 1). The absence of low temperatures, a protracted dry season and the presence of a closed nutrient cycle between the forest and the soil are the main factors accounting for the high net primary productivity levels recorded.

Although the potential is great there are several site specific features that severely limit crop and pasture production. One seldom considered fact about rainy tropical areas is the uncertainty of rainfall. The uniformity of air masses over the tropics and paucity of frontal systems account for much of the rain originating from convective clouds. Thus, some places receive heavy rainfall while nearby areas receive little. This contrasts to much of the frontal-generated rainfall in the temperate zone. Erratic rainfall is especially true in the large continental interior areas of the tropics, in contrast with coastal or island areas where orographic lift and land-sea breeze phenomena cause somewhat more spacial regularity (Lockwood 1974).

Soil variability in the rainy tropics is not well appreciated by agricultural scientists who have only general, small-scale maps to guide them (Moorman 1972). For example, the generalized map presented as "Soils of the Tropics" (Aubert and Tavernier 1972) at the scale of 1:47 million, identified only six suborders in this climatic area covering 1.7 billion hectares (Table 2). Kellogg (1950) predicted that as detailed soil maps become available, more distinct soil types would be found within the tropics than in the other parts of the world. As he pointed out, it is convenient to think that weathering masks the influence of parent rock on soil properties. However, it is our belief that the reality of soil variability has been masked by small scale reconnaissance soil surveys that portray a false sense of uniformity and serve only to widen the gap between scientists, who overinterpret such maps, and farmers, who know what their soils are like.

Where reconnaissance or detailed soil surveys are available, the great diversity of soils in humid tropical areas becomes evident. Reconnaissance surveys of part of the Amazon of Brazil (Falesi 1972; EMBRAPA 1975) and a detailed survey in part of the Amazon of Peru

Table 1. Estimate of net primary productivity of several ecosystems

| Ecosystem | Dry matter production (Tonne/ha/yr) | |
|---|---|---|
| | Mean | Range |
| Tropical rainforest | 20 | 10-35 |
| Tropical raingreen forest | 15 | 6-35 |
| Temperate summergreen forest | 10 | 4-25 |
| Tropical grassland | 7 | 2-20 |
| Temperate grassland | 5 | 1-15 |
| Freshwater swamp and marsh | 20 | 8-40 |

Source: Leith (1975)

Table 2. Major suborders found in the udic tropics, derived from small-scale maps (1:47 million) calculated by Orvedal and Ackerson (1972)

| Order | Suborder | Million hectares |
|---|---|---|
| Oxisols | Orthox | 750 |
| Alfisols | Udalfs | 40 |
| Ultisol | Aquults | 40 |
| | Udults | 410 |
| Inceptisols | Aquepts | 285 |
| | Tropepts | 185 |
| Total | | 1,710 |

(Tyler 1975) furnish ample evidence of variability at the regional and farm level. In fact, tropical countries with a significant proportion of rainy climates such as Colombia, Venezuela and Brazil, have all 10 soil orders of the U.S. Soil Taxonomy. While Oxisols and Ultisols are the dominant soils of such regions, high-base-status Entisols, Inceptisols, Alfisols, Mollisols and Vertisols occur in association with them along with localized areas of Spodosols, Histosols and even Aridisols in nearby arid regions (Lepsch et al. 1977; Paredes 1975). Consequently the common generalization about the low native soil fertility in the humid tropics, although valid, must be tempered by the presence of soils with high native fertility, on which much of the present agriculture is based.

A major misconception about the potential of the humid tropics is the exaggeration of the areal extent and importance of the presence of laterite or plinthite (Sanchez and Buol 1975). The literature contains numerous references indicating that after clearing, the dominant soils of the rainy tropics will turn into laterite rock within a few years (Gouru 1961; McNeil 1964; Goodland and Irving 1975). The geographical extent of plinthite occurrence in the tropics is quite limited. According to areas of mapping units reported in the South American portion of the World Soil Map (FAO-UNESCO 1971) plinthite, an iron-rich, humus-poor material capable of hardening into laterite on repeated wetting and drying, is found within the top 1.25 m in only 7% of the Oxisol-Ultisol regions of this continent, or about 69 million hectares. Plinthite in the subsoil is not a threat to plant growth unless the topsoil is removed by erosion. Hardened plinthite or laterite occurs as hardened rock outcrops at scarps between two erosion surfaces. This is a definite asset because such laterite caps provide slope stability as well as cheap and excellent road building materials. Unfortunately such outcrops are less prevalent in the udic soil moisture regimes (rainy climates) than in the ustic soil moisture regimes of the tropical savannas. We say unfortunately because the presence of laterite would significantly improve the quality of roads in regions such as the upper Amazon where stones are so scarce that they are sold individually.

The percentage and coverage of plinthite occurrence in Oxisol-Ultisol areas of South America (both udic and ustic) is actually identical to its occurrence in Ultisols of Southeastern United States. The North America portion of the World Soil Map (FAO-UNESCO, 1975) records a total of 8.5 million hectares of Plinthic Acrisols, which accounts for 7% of the Ultisol area of the United States. These soils are located in extremely productive areas of the Atlantic Coastal Plain of the U.S. in Georgia, the Carolinas, Virginia as far north as Washington, D. C. The lack of any plinthite or laterite threat is underscored by the 200 year plus agricultural history of the region and the present high yields of corn, soybeans, tobacco and peanuts.

Another way of estimating the potential of the rainy tropics is to examine some high experimental crop yields reported in the literature from these regions. Table 3 shows extremely high yields of the main annual and perennial crops, pastures, beef and lumber production, mostly under ideal experimental conditions. All compare favorably with those obtained in any region of the world. The yields of upland rice, elephant grass, and the two lumber species may be world records. It is interesting to note that the dry matter production of intensively fertilized and managed elephant grass (Pennisetum porposeum) surpassed the net primary productivity of all natural ecosystems reported in Table 1.

## PRESENT FARMING SYSTEMS

We define a farm system as the individual farm and with few exceptions, the productivity of present farming systems in the rainy tropics is low. Most grain crops average 1 tonne/ha, a fraction of those reported in Table 3. It is our contention that this gap is a result of lack of transportation and market infrastructure, and improved soil management systems.

Since no farm is organized exactly like any other, it is necessary to adopt some form of classification in order to facilitate a general discussion of farming systems. Ruthenberg (1971) has presented such a classification based on type and intensity of rotation, water supply, cropping pattern, implements of cultivation, degree of commercialization, and grazing patterns (Table 4). This terminology will be utilized in this discussion.

Although specific data of the relative importance of the various farming systems in the rainy tropics is not available, one can generalize from tropic wide data (Sanchez 1976) to say that some form

Table 3. Examples of high yields in rainy tropics of Latin America, without a significant dry season. Commercial yields are marked with *; others are experimental yields. Yields in tonnes/ha except for forest crops

| Crop | Yield (tonne/ha) | Location | Soil | Reference |
|---|---|---|---|---|
| Upland rice (grain) | 7.2 | Tingo Maria, Peru | Inceptisol | Kawano et al. (1975) |
| Upland rice (rain/yr-3 crops) | 10.0 | Yurimaguas, Peru | Alfisol | Kawano et al. (1975) |
| Irrigated rice (grain/yr-3 crops) | 18.0* | Guama, Brazil | Inceptisol | Alvim (1977) |
| Corn (grain) | 7.1 | Satipo, Peru | Alfisol | CIMMYT (1975) |
| Cassava (tubers) | 34.2 | Yurimaguas, Peru | Ultisol | NCSU (1973) |
| Beans (*Phaseolus vulgaris*) (grain) | 3.0 | Boliche, Ecuador | Inceptisol | Francis et al. (1976) |
| Soybeans (grain) | 3.1 | Yurimaguas, Peru | Ultisol | NCSU (1975) |
| Peanuts (pods) | 3.9 | Yurimaguas, Peru | Ultisol | NCSU (1975) |
| Cacao (beans/year) | 2.0* | Rondonia, Brazil | Alfisol | Alvim (1977) |
| Oil Palm (fruit/year) | 20.0* | Belem, Brazil | Oxisol | Alvim (1977) |
| Elephant grass (dry matter/yr) | 53.0 | Orooovis, Puerto Rico | Oxisol | Vicente-Chandler et al. (1974) |
| Beef (liveweight gain/yr) | 1.2* | Sorocovis, Puerto Rico | Oxisol | Vicente-Chandler et al. (1974) |
| *Gmelina arborea* ($m^3$ lumber/ha) | 38* | Jarilandia, Brazil | Oxisol | Alvim (1977) |
| *Pinus caribaea* ($m^3$ lumber/ha) | 27* | Jarilandia, Brazil | Oxisol | Alvim (1977) |

Table 4. Definition of farming systems after Ruthenberg (1971)

| Term | Description |
|---|---|
| Collecting: | Hunting, fishing, gathering of wild cacao, rubber, hard timber |
| Cultivation: | |
| a. Type of Rotation | |
| Fallow system | Long term wild vegetation |
| Ley system | Grass pasture for years between crops |
| Field system | Established field rotations |
| Perennial crop system | Cacao, sugarcane, sisal, tea, coffee |
| b. Intensity of Rotation | |
| (R = crop years/total years x 100) | |
| R = <30 | Shifting cultivation |
| R = 30-50 | Semi-permanent cultivation |
| R = 50-70 | Stationary cultivation with fallow |
| R = >70 | Permanent farming |
| c. Class of Water Supply | |
| Rain-fed | Only natural rainfall |
| Irrigation | Adding some water |
| Dry | Has a fallow period |
| d. Degree of Commercialization | |
| Subsistence farm | <25% of gross is sold |
| Partly commercialized | 25-50% of gross is sold |
| Semi commercialized | 50-75% of gross is sold |
| Highly commercialized | >75% of gross is sold |

of shifting cultivation is the most prevalent. Most of the farms are subsistence or only partly commercialized and depend solely on rainfall. Permanent and more highly commercialized farming is more prevalent in better soils (Grigg 1974) which are easily identified as the high base status soils (Sanchez and Buol 1975). These are well known to soil scientists but probably best summarized by Kellogg (1950) when he identified the conditions of relatively fertile soils in the humid tropics as:

1. soils occasionally rejuvenated by volcanic ash;
2. soils on steep slopes underlain by parent rocks that contain a supply of plant nutrients and eroding at rapid enough pace to remove leached material and expose the relatively fresh material;
3. soils developed from highly basic rocks with adequate rates of erosion to remove surface soils;
4. soils in flood plains that receive material from one of the above conditions and are not too frequently inundated by flood waters or high water table.

One or more of the above conditions exist in all of the areas in the rainy tropics that are presently densely populated. Many of these areas have attained a highly structured and efficient society based largely on many small, partly to highly commercialized permanent farms practicing field or perennial crop systems (Table 4).

Area wise, however, most of the rainy tropics are sparsely populated with shifting cultivators operating subsistence farms or extensive cattle grazing, both on low base status soils. A fallow system, with release of nutrients upon burning the wild vegetative biomass, is an almost universal practice of obtaining the bases needed for crop or pasture production. The large land requirements for this type of operation precludes dense populations.

The dominant farming system in the rainy tropics is still shifting cultivation. It can be defined as an agricultural system in which temporary clearings are cropped for fewer years than they are allowed to remain fallow. Shifting cultivation is estimated to cover approximately 30% of the arable soils of the world (1.2 billion hectares) supporting over 250 million people, approximately 8% of the world's population (Sanchez 1976). Although the details vary with locality, its principal features are essentially the same throughout the humid tropical forested areas. Small fields are cleared by hand during the periods of least rainfall, and are burned just prior to the first rains. Without further land preparation or removal of debris two or three crops such as rice, corn, beans, cassava, yams and plantains are planted. Some manual weeding is practiced, and the only fertilization received comes from the ash produced by burning the forest. After the first harvest of sole crops or intercrops, yields decline and the fields are abandoned to the rapid forest regrowth. The forest fallow may grow for 4 to 20 years before it is cut again.

Farmers abandon these fields when productivity declines. Figure 1 shows examples of yield declines of various crops under different soil and climatic conditions. Yield declines are faster in low base status Oxisols and Ultisols than in high base status soils because of the faster decline in soil fertility parameters (Sanchez 1976). Weed growth is another important cause of field abandonment. It is more important in high base status soils because they are also a good medium for weed growth.

Shifting cultivation is a stable and efficient farming system in low population density areas. The efficiency is based in the use of the most limiting resource: energy. Shifting cultivators expend one calorie of labor energy to produce 16 calories of food, while U.S. farmers spend 1 calorie of fossil fuel to produce only 3 calories of food (Greenland and Herrera 1977).

Other important systems in the humid tropics include capital-intensive plantation systems, which produce most of the bananas consumed in the temperate regions, and crop-pasture and crop-timber successions (Greenland and Herrera 1977).

It is tempting to debate the relative merits of the various systems. The agricultural or social scientist, trained and nurtured in the highly commercialized farming systems of the developed countries often seeks to change the apparently inefficient techniques he finds in the rainy tropics. Scientists armed with such facts as the net primary productivity of tropical forests or even the high yields frequently recorded, overlook the major reasons of low productivity, namely the limitation of diet and economics (Whittaker and Likens 1975).

Because the daily routine dictated by the climatic, social and occupational activities contrasts with that familiar to the scientist, he frequently blames the personal ambition and/or creativity of the local farmer. This is totally unrealistic if one considers that the present farming systems have evolved through trial and error and "survival of the fittest" for many generations.

We more nearly subscribe to the hypothesis of Schultz (1965). He assumes that farmers, in their present state of knowledge, are fully utilizing the land and labor available and that the rate of return on investment to increase production in traditional agriculture is so low that there is little incentive to acquire credit or increase savings needed to change. Thus, to change traditional farming systems, a supply of new agricultural inputs that have a relatively high rate of financial return must be available to the farmer and he must learn the technology of how to utilize these inputs. Put more simply, to increase production of subsistence and partly commercialized farmers, incentives are needed (Mosher 1969).

The basic energy of all farming is the sun; thus the process of farming requires large areas, making transportation a necessity between the fields and the markets. Only if a profitable market is available will the farmer adopt new technologies and then he will adopt only those technologies that produce a sizeable, low risk, return on his investment.

Farming decisions are made by farmers. Arnold and Bennett (1975) point out that farmer decisions are primarily based upon their own evaluation of probabilities, not any remote source of data. They go on to point out that by some personal balance of economics and sociology, each individual farmer makes a choice. The only clear generalization that can be made about that choice is that it will be in the direction where the farmer perceives the least risk. Normally risk increases with investment, and to avoid risk, one must avoid investment or inputs into the farming operation. In some cases investment capital is not available. In other cases it is not available in sufficient supply to warrant, in the farmers' opinion, which is the only one of importance, the risk probabilities.

## IMPROVED FARMING SYSTEMS

At the risk of oversimplification, we would reduce the variables necessary to increase productivity to two components: 1) There must be a reason to increase production and that reason must be conveyed to the farmer in terms of his self betterment; 2) The technologies of increasing production must exist and be within the farmer's ability to use them.

Let us first try to analyze the problems of conveying a need for increased production to the farmer. Spedding (1975) concluded that agricultural systems are too large for controlled experiments but are not necessarily complex. An all too common occurrence, however, is the failure to conceive the size of an agricultural system. If we attempt to analyze an agricultural system farm by farm, road by road, market by market, it is analogous to examining a forest molecule by molecule.

Every person in the world is part of the agricultural system because he eats. Without losing sight of this fact we must conceive how certain parts of the world, namely the rainy tropics, can function as a part of the total agricultural system. It is, and will continue to be, increasingly difficult to isolate the rainy tropics or any other part of the world. Improved transportation and communication systems, that can presently deliver cut flowers from Bogota, Colombia to supply 25% of the U.S. carnation market, can deliver staples to the market place in any part of the world. Thus, the world price of staples cannot be divorced from the farming system decisions in the rainy tropics. Each part of the rainy tropics must find its own niche in worldwide agriculture.

All farming systems essentially evolve in the mind of the farmer. What he does depends upon how he perceives and evaluates the alternatives. Although on the average he tends to minimize his risk, he is not totally opposed to taking some risk. Some parts of the rainy tropics require more risk than others.

The largest single potential are the areas of low base saturated infertile Ultisols and Oxisols that are well supplied with rainfall and of satisfactory temperature for a wide range of production. Risk capital in these areas is mainly for lime, fertilizer, transportation and education.

Large amounts of risk capital are required to open these areas for increased production. But, it can be done and we would point to the bold move that placed Brasília, Brazil, in the hinterlands of infertile savanna Oxisols. The infrastructure of roads and communications that followed has spawned extensive farming development. What impact the Transamazonia highway system will have on the Amazon region is not yet known. Much will depend on the extent to which agricultural capital can receive returns on its investment in that area. Projected returns on investments in these areas are very long term.

The second requirement for improving farming systems in the rainy tropics is that technology must be available for increasing production. We put this as the second and not the first requirement because without the necessary incentives of transportation and market infrastructure, the traditional farming systems are likely to remain as such with very minor modification.

Improved farming systems in these regions must meet the following requirements modified from those outlined by Greenland (1975):

1. The soil fertility levels must be improved by modest application of fertilizers and lime to satisfy the needs of crops adapted to the environment.
2. Nutrient removal by crops or loss processes must be replenished and increases in acidity corrected by periodic lime applications.
3. Soil physical conditions, suited to the farming system used, should be maintained.
4. The system prevents buildup of weeds, pests and diseases.
5. Soil erosion is controlled.

Research conducted independently by the International Institute for Tropical Agriculture in Ibadan, Nigeria and by the North Carolina State University Tropical Soils Program in Yurimaguas, Peru have produced the basic components for successful continuous crop production systems in the humid tropics, meeting the criteria previously specified. These are described in the IITA Annual Reports (1972-76), the NCSU Annual Reports (1973-76) and review articles by Greenland (1975), Lal (1975), Lal et al. (1975), Sanchez (1975, 1976, 1977). The basic components of the system are:

1. Avoid mechanized land clearing, because it causes serious topsoil removal, soil compaction and increases susceptibility to erosion even in flat areas. The traditional slash-and-burn land clearing method prevents this problem and provides free fertilizer in the form of ash. (In high pH Alfisols of West Africa, excessive ash fall may cause micronutrient deficiencies).

2. Keep the soil covered all the time if possible, either with a standing crop, mulches and/or with successful intercropping systems. This will reduce excessively high surface soil temperatures, conserve water and nutrients, minimize weed growth, and prevent excessive erosion even on relatively steep slopes.

3. Reduce excessive soil acidity levels by liming to pH 5.5 after the first crop and apply the necessary amounts of basal phosphorus fertilization at that time. Maintain fertility levels of other nutrients in adequate amounts to meet crop requirements.

4. Use crops and varieties that are tolerant to acid soil stresses encountered in Oxisols and Ultisols, particularly aluminum toxicity and low phosphorus availability in order to keep investment in fertilizer and lime to the minimum.

5. Develop cropping sequences or crop-pasture sequences that maximize the use of land, particularly, intercropping systems and prevent buildup of pests and diseases at the same time.

With these components, shifting cultivation can be transformed into economically sound continuous farming systems, producing yields of rice, corn, cassava, and grain legumes, which double or quadruple actual production levels, although not as high as those shown in Table 3. These cropping systems need to be projected towards crop-pasture successions in areas where beef production is possible, and for the establishment of permanent crops and commercial timber. With the proper use of improved grass-legume pastures and fertilization, beef production in the Pucallpa region of the Amazon Jungle of Peru has reached levels as high as 300 kg/ha of annual live weight gain (Santhirasegaram 1976).

What would be the total impact of full utilization of modern technology, properly applied to suitable soil areas in the rainy tropics? Present production fitures (Sanchez 1976) indicate that in rainy tropical areas about 0.3 ha/capita is cultivated. Although difficult to verify because reality always overtakes data collection, it appears that in the rainy tropics about 5% of the Ultisol-Oxisol areas are cultivated whereas about 25% of the high-base-status soils are cultivated at about the same land area needed per capita. Applying enough lime and fertilizer to improve the low base status soils to production levels equal to present production on high base status soils, should feed 600 million people by increasing the use from 5% to 25% of the area.

Average farmer yields in the rainy tropics are low compared to what has been obtained in experimental fields and production could be increased many times the present levels (Buringh et al. 1975). Both increased yield per unit land and increased land area under cultivation are possible in the rainy tropics. The predominantly high base status Asian rainy tropics with 27% of its land cultivated appears more prone to improving yield/unit land (Van Liere 1977). Predominantly low base status tropical America, with only 5% of its land cultivated, appears headed for both increased area of cultivation and increased yield/unit land.

We wish to emphasize that the application of technology requires ability on the part of the farmer. He has to make the day by day decisions. No amount of training can completely substitute for individual ability to make decisions without supervision. With the present returns from farming so low and lack of education in rural tropical areas often neglected, the farmers presently in traditional subsistence farming are seldom prepared for many of the available technological advances. Lack of research and extension facilities, and the multitude of farmers forces technology to be aimed at an average farmer and an average farm. The deviations from an average farm are extreme even within limited distances. Failure to communicate with the farmer on his terms greatly limits the application of new technology. One must also consider that a single package of practices in any area fails to realize the micro soil variations as well as the social-economic differences of individual farmers, plus exposing the entire area to the hazards of weather, disease, market fluctuations, etc. Diversity of practices normally provided by the inherent independence of the people who farm provides a viable hedge against such hazards. Their regimentation reduces this safety factor.

Problems of communications with farmers are not easily solved in the rainy tropics. While a very high proportion of the men listed in Who's Who in Science were reared on farms (Kemper 1970), practically none have been reared in rural rainy tropical areas. Thus, agricultural scientists and more importantly, extension scientists have to overcome strong social barriers that separate peasant farmers and academics. Farming abilities and "language" learned at an early age greatly enhances a scientists' ability to communicate technology to farmers.

Areas of present high population densities can, in theory, benefit greatly and rapidly from technological advancements. Historically these areas move very slowly. Sociological inertia is great and education is needed to understand technology. Simple technologies requiring low capital risk are best suited to these areas. Development of scientists that know farm problems from childhood should be part of the long term goal.

There are less-entrenched sociological problems in the thinly populated Oxisol-Ultisol areas. Few of the farmers presently in these areas have the skills necessary to implement the modern technologies these soils demand, although at present, migration from developed areas of southern Brazil to the Amazon Basin is promising. Since the regions are remote from areas of consumption, transportation is vital and beyond the capacity of the farmer to provide. It seems rather passé but it must be reliable transportation. Reliable transportation of produce is thus the first and most obvious requirement. Transportation is also the foundation of communication. A market price that is stable enough to satisfy the farmers' fear of risk must be at the end of the transportation. This is a more difficult problem than transportation.

## CONCLUSION

There is a story in agricultural circles of the USA that goes something like this. The corn belt farmer is watching his corn suffer from drought and the newspaper reporter drives up to ask the inevitable question, "When do you think it will rain?" Based upon years of experience the farmer replies, "It always rains before it's too late to save the corn."

It is in this way we see the rainy tropics responding to the world need for food and fiber. The world has to be in enough need that it assures a return on the investment needed to convince the rainy tropical society, president to peasant, that the risk they undertake for education, infrastructure and fertilizer is reasonable. Depending on local situations, and global prices of energy, they will select the method of increasing production - labor intensive methods if energy prices are high, and energy intensive methods if energy prices are low. Within the rainy tropics the potential for production is almost unlimited but development of that potential will take place only as fast as the critical needs of the world dictate that the necessary guarantees of profit are made to the farmers.

The limited potential of the rainy tropics for food production because of unfavorable climate, low fertility soils, laterite formation, etc., is a myth. All myths die hard. The words of Kellogg (1960) provide a better conclusion than these authors can write:

> "Certainly none of us would think of estimating the potentialities for production of soils in temperate regions on

the basis of non-scientific management. Suppose we looked at native production of Holland, Belgium, Florida, even the midwest of the U.S. without fertilizer, insecticides and plant breeding?"

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## SUMMARY

Science and technology have demonstrated that high crop yields are possible in many areas of the rainy tropics. No single physical constraint can be identified as limiting future production potential of the area as a whole. However, each farming system is site specific with respect to physical constraints, technical competence, economic capability, and socio-political incentive to overcome the constraints. The potential productivity of the rainy tropics far exceeds present productivity. Some technological principles and practices are presently available that permit higher farming productivity with ecological compatibility in many parts of the rainy tropics. Future research and education will help expand present productivity.

## RÉSUMÉ

Grâce à la science et à la technique, de nombreuses régions tropicales, de fortes pluviosités, peuvent obtenir des rendements agricoles élevés. On n'a pu identifier aucune contrainte physique qui à elle seule limiterait le potentiel de production de la région dans son ensemble. Toutefois, chaque système de culture doit s'adapter dans l'espace, selon les contraintes physiques, le degré de technicité, les possibilités économiques et les mesures d'incitation socio-politiques accessibles pour surmonter les contraintes. Les potentialités de production des zones tropicales pluvieuses dépassent de loin leur productivité actuelle. On dispose actuellement de principes et de pratiques techniques qui autoriseraient dans de nombreuses parties de ces régions, un relèvement de la productivité agricole compatible avec la préservation du milieu. La recherche et l'éducation aideront à réaliser cet objectif.

## ZUSAMMENFASSUNG

Naturwissenschaft und Technik haben bewiesen, daß in vielen Gebieten mit tropischen Regenklimaten hohe landwirtschaftliche Erträge erzielt werden können. Kein einziger physischer Beschränkungsfaktor ist bis jetzt gefunden worden, welcher sich gesamthaft gesehen als limitierend auf das künftige Ertragspotential solcher Gebiete auswirkt. Jedoch ist jedes Bebauungssystem in Hinsicht auf Ertragshindernisse, technisches Können, wirtschaftliche Möglichkeiten und soziopolitische Bereitwilligkeit zur Überwindung der Hindernisse standortspezifisch. Die Ertragsfähigkeit der Regentropen liegt weit über dem gegenwärtigen Ertrag. Es stehen gegenwärtig verschiedene technische Prinzipien und

Verfahren zur Verfügung, mit deren Hilfe sich die landwirtschaftliche Porduktion ohne ökologische Nachteile steigern läßt. In der Zukunft werden weitere Forschungen sowie landwirtschaftliche Schulung und Ausbildung zur Ertragserhöhung beitragen.

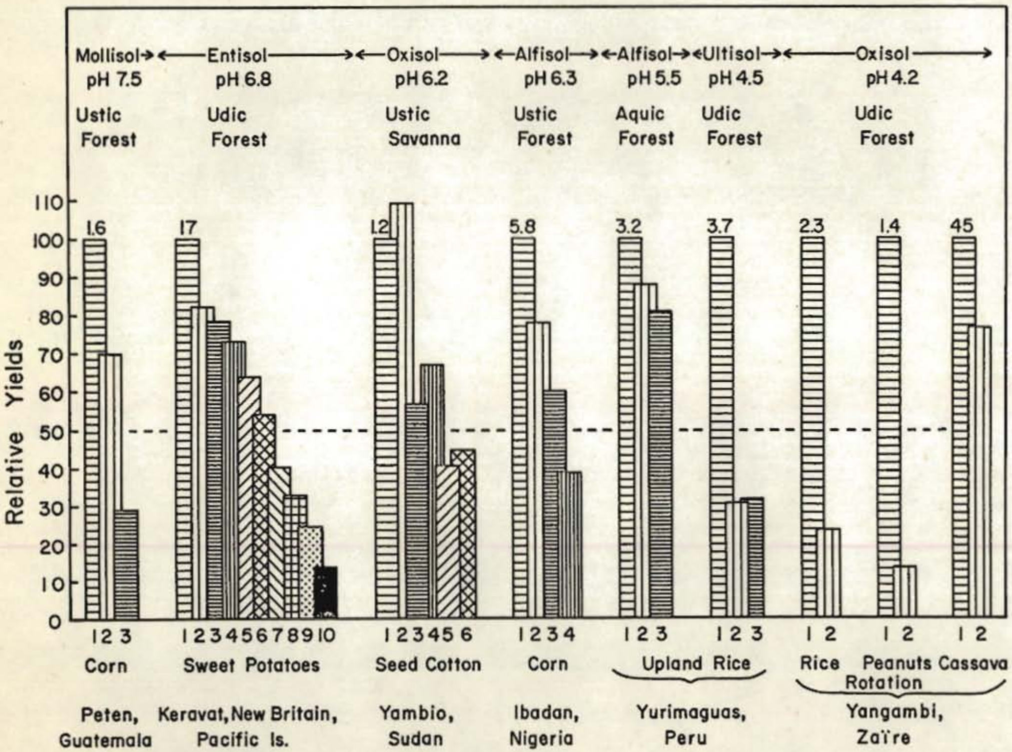


Fig. 1. RELATIVE RATE OF YIELD DECLINE (AFTER: SANCHEZ, 1976)

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