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Identifying Technological Potentials

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The potential for food production in sub-Saharan Africa far exceeds current production. Low soil fertility is among the principal causes of low yields. Intensification of agriculture and further expansion of the cropped area requires more external inputs, which often are not available to the rural farmer or are too expensive. As a result, yields per unit area are not increasing, area expansion occurs slowly, and food production grows at a slower rate than the population.

This situation presents an urgent challenge to agricultural research to develop improved varieties of crops and new husbandry and management techniques that offer farmers better means of production. Much research has been carried out in Wageningen to quantify crop production under a wide range of conditions. Rather than follow an empirical route, fundamental principles from several scientific disciplines have been used to calculate crop growth rates (Penning de Vries and van Laar 1982; van Keulen and Wolf 1985).

AGGREGATE BIOLOGICAL POTENTIAL FOR FOOD PRODUCTION

Under optimal conditions, differences in biomass production among various crops of similar species are remarkably small. For example, under optimal conditions for growth, maize fixes about 5 percent of the visible part of incident solar radiation, which results in an increase in biomass of about 300 kilograms of dry matter per hectare per day. For a main growing season of 120 days, such a crop may produce 14 tons of grain per hectare, assuming that about 40 percent of the final biomass consists of grain. Allowing time for the farmer to prepare the field and for seeds to germinate and produce a full canopy requires about half a year. If a second crop can be grown the same year, annual production is twice as high.

The figures for maize also apply to other tropical cereals and grasses, such as sorghum and sugarcane. Maximum growth rates for most other crops, including wheat, rice, and all leguminous and root crops, are about 35 percent lower. The main product in leguminous and root crops can compose more than half the total biomass. Growth duration for any crop species depends on variety and environmental conditions.

About 30 percent of the total land area in sub-Saharan Africa is suitable for cropping (Linnemann et al. 1979). However, conditions are not optimal for crop production in substantial areas because soils are shallow, rocky, on a slope, or present physical or chemical problems. Year-round cropping is possible in humid regions, but the growing season in semiarid zones is short. Rivers and lakes offer opportunities for irrigation. The remaining 65 percent of the land area includes extensive and valuable rangelands.

In order to analyze production potentials, the African continent south of the Sahara has been divided into 27 broad regions, each with relatively uniform conditions of soil and climate. Taking into consideration soil and climatic constraints, but assuming optimal conditions for nutrients, disease, and weed control, Buringh and colleagues calculated that the crop production potential on rainfed fields in these regions ranges from 10 to 60 percent and averages 40 percent of the potential under continuously optimal conditions (Linnemann et al. 1979). The highest percentages are generally found in the most humid zones, the lowest in the semiarid regions. Potential grain production per year for the whole of sub-Saharan Africa was calculated at 10 billion metric tons. This amount could support about 10 billion persons at a West European level. The current population is about 450 million, which indicates massive physical potential for increasing food production in sub-Saharan Africa.

ASSESSMENT OF SPECIFIC TECHNOLOGICAL POTENTIALS

Increasing food production in Africa requires putting more land into production and raising yields. The central problem is that both increasingly require material inputs other than those locally available or too expensive for the farmer. Assuming that much can be done without these inputs is against all agricultural experience. An important challenge for agricultural research in Africa is to determine the most that can be done with the fewest external inputs. This will require considerable research, since climate, soils, and preferred crop species differ widely, and relatively little experience has been gathered in tropical regions outside irrigated areas.

Our group in Wageningen is attempting to develop an approach to raising yields based on a systematic analysis of cropping and farming systems. First of all, it should be recognized that only a few environmental factors determine the rate of growth of a crop, but these factors vary from place to place and time to time. When there is continuous and ample water and nutrients, absorbed radiation is usually the principal growth-rate determinant. This is the situation in the modern, very intensive agriculture of some developed countries and in some irrigation projects. Where water is not continuously present or is insufficient but where nutrients are nevertheless in ample supply, growth rates may still be little affected by seasonal climates, but the duration of the growing season is reduced. It is then of critical importance to quantify the water and soil balance. This situation is found in some of the drier semiarid zones and can be created in all of them by fertilization. The main practical problem, then, is to manage the crop in such a way that soil water is not exhausted before the crop ripens.

In a production situation in which nitrogen and phosphorus are not available in sufficient amounts, the total biomass grown in a season is often directly proportional to the quantity of nitrogen absorbed by the crop. If enough phosphorus cannot be absorbed from the soil, nitrogen uptake becomes reduced, and yield is lowered. In subsistence farming, nitrogen and phosphorus often are in short supply; deficiencies of other plant nutrients may occur as well, depending on the type of soil. Generalizations are difficult, except that deficiencies of other nutrients are bound to develop after several years of fertilization with nitrogen and phosphorus only.

A systematic, multidisciplinary analysis along these lines was applied to the Sahelian zone, where, at 500 millimeters annual rainfall, the average annual production of rangelands is about 1,500 kilograms per hectare of low-quality forage (Penning de Vries 1983). It was predicted that this low production was caused primarily by soil poverty rather than by low rainfall, and that fertilization could bring production up to only about 5 thousand kilograms per hectare of good quality grass forage. This was fully confirmed afterward. The systematic analysis showed also that crop yields in this area can be boosted to a high level by irrigation plus fertilization. This was later confirmed experimentally.

A proper supply of nutrients and appropriate management techniques generally increase the efficiency of irrigation considerably. Consistent with our analysis was the observation that poor soil would allow only a meager 2,500 kilograms per hectare of very low-quality biomass to be grown if irrigation is applied without fertilization. It was shown that without external material inputs little technical improvement can be made in the transhumance and sedentary animal husbandry systems (Penning de Vries 1983; Breman and de Wit 1983). Use of fertilizer on rangeland, however, does not pay. The most promising input to improve Sahelian animal nutrition seems to be the use of phosphate fertilizer on leguminous crops grown for seed and forage.

There are several advantages to a systematic analysis of crop production situations from the agronomic standpoint. First, it is faster than trial and error only. At the current stage of development, this approach certainly does not replace field trials but leads to more efficient and goal-oriented experimentation. Second, it makes much more use of the vast knowledge in fundamental sciences. This linkage provides the opportunity to consider the implications of elements of technology in the design stage that cannot be handled by field workers, and it provides the opportunity to react within an established framework to suggestions from field workers and farmers.

Third, such an analysis allows use of knowledge from outside the study area. Evaluating a technology in other environmental conditions, assessing the impact of modification of parts of it, and testing the stability of results in a varying environment can all be speeded up considerably. Fourth, it allows elaboration of the options of agronomic development in an area: it can give quantified answers to *What if?* questions. Still, it should be emphasized that frequent reference back to basic science and careful evaluation and supplementary research in the field are necessary.

TECHNOLOGICAL ISSUES IN ACHIEVING POTENTIALS

The preceding chapters in this book raise a number of key issues for understanding and exploiting the technological potentials for food production in sub-Saharan Africa. There is also the question of what crop species to promote. According to Paulino's chapter, maize, rice, and wheat supplied about 26 percent of sub-Saharan food production in the early 1960s, millet and sorghum about 28 percent, and root crops 27 percent. As we already know how to increase productivity of the first three crops, more emphasis on them might be particularly effective in the short run.

Potential Yields

Ter Kuile notes that despite the increased availability of water and decreased drought risk, conditions for agriculture in humid climates are worse than in semiarid areas. The main reasons for this are increased land reclamation, imbalances in soil nutrients, and diseases and pests. The negative effect of lower solar radiation in humid areas may be more than offset by a longer growing season. This is not reflected in the data presented by ter Kuile, which refer to crops with a fixed growing season.

Some of the potential biomass growth rates quoted by ter Kuile are only a fraction of the high rate of 300 kilograms per hectare per day mentioned above for tropical grasses such as sorghum, millet, and maize. Potential biomass growth rates for leguminous crops, wheat, rice, and tree crops (grown in an environment to which they are adapted) are about 150 to 200 kilograms per hectare per day. In most cases, these potential growth rates exceed maximum observed rates, particularly in the humid tropics. We believe that this is entirely due to lack of nutrients, to pests and diseases, and to suboptimal management of crops and soil. This emphasizes that research should concentrate on improved techniques of production in the more humid areas.

Water Control

Uncertainty about the beginning and duration of the growing season is greater in Africa than in many other parts of the world, particularly in African zones with a distinct dry season. Because of variability in distribution and amounts of precipitation, the chances for crop damage are relatively large. Except where irrigation is feasible, the uncertainty of precipitation is an important factor to consider in any improved food production technology. Some means of providing early warning of crop damage or failure must be provided. In addition, there is a need for storage and transport facilities with a larger capacity per capita than in other parts of the world.

Increasing the amount of available water in the soils of semiarid regions may prolong the effective growing season, but perhaps more importantly it reduces chances of crop failure. Runoff of 40 percent and more is common in West Africa and probably also in semiarid zones of East Africa. Techniques to reduce runoff and increase infiltration are being evaluated. Reduction of evaporation will have a similar effect in semiarid zones, where much more water is lost by evaporation from the soil surface than by transpiration. Both are being considered in combination with weed suppression techniques. Improved infiltration improves water status—and thus crop establishment—on deep, fine soils. Shallow and coarse soils, however, will remain drought prone during the entire growing season because of low water storage capacity. Improved infiltration on those soils would lead to increased drainage and greater leaching of plant nutrients, which would tend to reduce productivity. On heavier soils, particularly in humid zones, drainage is a big problem. To avoid low efficiency of nitrogen fertilizer, waterlogging should be avoided, especially early in the season.

Nutrient Deficiencies

The rooted layer of the soil generally contains much more nitrogen and essential minerals than the amount crops extract during a growing season. Nevertheless, their uptake is much less than what is needed to attain potential growth. Actual availability of these nutrients to plants is low due to various microbiological, chemical, and physical processes. Although the processes underlying soil fertility are not yet adequately understood, their importance to sustaining food production and soil conservation is beyond doubt.

The classical approach to soil fertility problems is to study the effect of fertilization by field trials. This has been done in all African countries, with quite variable results. Long-term field trials tend to show declining fertilizer effects, possibly because of recommendations for application. Fertilizer effects can be improved by making application recommendations specific to soils and crops and by composing artificial fertilizers so as to nullify their decline in efficiency. Also, the field trials often included application of organic manure, which researchers considered to be readily available. However, farmers have increasingly less manure and increasingly larger cultivated areas, so that the use of manure may be only a very local solution.

Balance studies are another approach to soil fertility analysis. They are based on the notion that, in the long run, crops cannot absorb more nitrogen and minerals than are made available. On poor soils like those in most of sub-Saharan Africa, the long run may be only a few years, since available nutrients will quickly be reduced below the level necessary to sustain cropping. Crops almost always extract more nutrients than become available in the soil by natural processes. The rate at which nitrogen is supplied by leguminous plants, microorganisms, and airborne nitrogen compounds is fairly low. It can be increased by stimulating leguminous crops through fertilization with phosphorus. But the natural supply of phosphate is very small in many African soils. It must be added to most soils in quantities much larger than those crops extract, at least for a considerable number of years.

The soil may release micronutrients sufficiently fast to meet crop needs for tens or hundreds of years. Magnesium and potassium availability can be an intermediate situation. Although fertilization trials of a few years may not show any crop response to additions of these nutrients, deficiencies develop in the soil over time if growth limitations imposed by nitrogen and phosphorus are removed. Extensive experimentation in western Africa shows that yields often declined in the semiarid areas after a few years of continuous cultivation in spite of fertilization (Charreau and Nicou, 1971; Pichot et al. 1981). However, micronutrients were not applied in those long-term trials, which may have been the major cause of the observed decline in yields. Future experimentation should address this matter thoroughly, because improving and then maintaining fertility is an absolute necessity in any new food production system.

A combination of the experimental and balance study approaches has been applied successfully to areas in tropical South America where soils and climate are similar in many respects to those of the humid tropics of Africa. In the acid soils of Peru and other tropical humid South American areas, it was found that a proper application of nutrients maintained or increased production of 10 to 20 successive crops (Sanchez et al. 1982; Sanchez and Bandy 1982; Benites and Valverde 1982). In that case nitrogen, phosphate, potassium, and magnesium were applied at rates of 10–100 kilograms per hectare per year. The micronutrients copper, zinc, barium, and molybdenum were applied at a rate of 0.01–1 kilogram per hectare per year. Lime was applied to stabilize soil acidity.

An attempt to apply this Yurimaguas technology to African conditions seems worthwhile.

Improvement of Soil Fertility

Shortage of phosphorus in the soil leads to a low rate of uptake of nitrogen and a low growth rate. At first it may even be mistaken for nitrogen deficiency (Penning de Vries and Djiteye 1982). Low nitrogen uptake due to phosphorus deficiency is probably fairly widespread in sub-Saharan Africa. Consequently, use of phosphorus fertilizer on a large scale on many of the African soils is strongly recommended. It is often useful and never harmful when applied at low or moderate rates. It will improve the productivity of legumes directly and of cereals and grasses indirectly. The productivity increase may not be spectacular, but gains of 5 to 20 percent seem realistic. Moreover, application of phosphorus does not require new technologies and can be introduced relatively quickly. Phosphate fertilization assistance may be one of the most effective forms of aid from donor countries over the long run.

The long-term effect of application of phosphorus may be as important as the short-term effect. For example, sandy areas of Drente in the Netherlands had become overcropped by the end of the last century because of increasing population (Edelman 1943). The exhausted soils produced little and had developed many completely barren spots. Living dunes over extended areas caused great problems, and efforts to establish forests to stabilize them failed. Application of cheap phosphate fertilizer (basic slag, a byproduct of iron production), followed by nitrogen fertilizers, halted the decline of production. Some of those lands are now among the most productive in the country. The positive effect of fertilizer was not limited to agriculture alone but protected the environment as well.

When urea, a common form of nitrogen fertilizer, oxidizes into nitrate, the form in which it is absorbed by plants, it acidifies the soil. If unchecked, root growth will be hampered within 5 to 20 years, either directly or indirectly—by the increased concentration of dissolved aluminium to phytotoxic levels. Application of lime is an appropriate and well-known countermeasure. Unfortunately, rather large quantities of lime are required, from a few hundred to a thousand kilograms per hectare per annum. Just hauling these amounts poses an extra burden on African transport facilities.

There is good evidence that rhizosphere microorganisms associated with rice crops fix aerial nitrogen in poor soils at a rate high enough to maintain moderate paddy yields of about 1 thousand kilograms per hectare for long periods without fallow (IRRI 1983). However, this fixation ability is related to flooded, anaerobic conditions, and it is not likely that breeding or genetic manipulation will allow other crops growing in nonflooded conditions to do the same. Creating effective associations of nitrogen-fixing Rhizobia strains with other crops through genetic manipulation is an intriguing challenge but is highly unlikely to have any impact on food production in sub-Saharan Africa in this century (Cocking et al. 1982).

The capacity of trees to bring nutrients up from deep in the soil is quite limited. Although a few tree roots may extend downward tens of meters, most are at about the same level as those of annual crops. Moreover, much of the nutrients absorbed serve the trees; they benefit crops only indirectly. However, the importance of trees in nitrogen fixation is beyond doubt.

Proper tillage not only controls weeds but also improves the soil and water relationship and may accelerate release of plant nutrients from the soil. This allows a crop to extract nutrients for a longer period and to produce more. Improved tillage, like other forms of intensification, increases production. Without appropriate fertilization, however, the positive effects last only a few years and also lead to a more rapid impoverishment of soils. This reinforces the vicious circle described by Collinson: reduced productivity pushes the farmer to cultivate larger fields, which implies less organic fertilizer per unit surface and quicker soil exhaustion.

Collinson emphasizes that farmers are unable to cultivate more than a small fraction of their land at the most appropriate time because of the low capacity of draft animals and the hand hoe. Consequently, the bulk of the crops are established at suboptimal times. Mixed cropping, then, reduces the need for time-consuming weeding operations. But apart from the labor use issues, mixed cropping generally does not lead to a technically more effective use of environmental resources than single crops when planted at the same total density (de Wit et al. 1979). Clearly, research to determine optimal mixtures should emphasize advantages other than technical yield—such as expected financial returns and risk avoidance.

CONCLUSION

The issue of the productivity of agricultural research is addressed by several chapters in this book. The main theme is the inadequacy of the link between farmer and researcher and the inefficiency that this causes in both the development and in the adoption of new technologies. This chapter develops a different, although complementary, theme. Agricultural research methodologies typically derive from an era when the knowledge of the sciences involved was fragmentary. This is no longer the case. Today we have extensive, albeit imperfect, information on many aspects of these systems.

The efficiency and progress of agricultural research could be significantly improved if the research agenda were based on a careful and systematic analysis of current biological and physical data. This approach would allow more effective transfer of fundamental findings between differing agricultural environments and between nations. Lines of research unlikely to be productive could be screened out at an early stage of the research process, thus keeping researchers and resources concentrated in the most promising areas.

Various applications of this approach in both the African and the Latin American context demonstrate that it has practical applications. Overall, the approach eliminates some of the randomness from the experimental method and speeds up the development of improved agricultural technologies.