Plant Production (Group Lotus)

Biological measures for the improvement and sustainability of tropical soils

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Abstract

The improvement of the food situation in the tropics will depend on reliable production methods adapted to the various conditions of these regions. Besides appropriate technologies for crop management practices, the conservation of soil-biological resources deserve special attention aiming at sustainable soil productivity. The present review emphasizes the importance of the use of the biological properties of the plants such as symbioses and semi-symbioses which substantially improve the exploitation of the macro-nutrients phosphorus and nitrogen in soil for plant nutrition. Thus, enabling a more economic utilization of expensive phosphorus and nitrogen fertilizers specially under the precarious soil conditions in the tropics. The author demonstrates the key role of biological measures under various stress conditions in relation to research activities of the „Institute for Crop and Animal Production in the Tropics“ in Goettingen, and further research needs, with primary emphasis on two distinct tropical environments: the humid and arid/semiarid tropics.

Background

- Growing malnutrition, i.e., both inadequate and unbalanced nourishment, is the most pressing problem facing the majority of tropical and subtropical countries
- The demand for food is rising all the time as a result of the ever-increasing rate of population growth.
- Estimates by the FAO indicate that in order to maintain even the present level of supply, which everybody knows is insufficient, food production in the tropics will have to increase by at least 60 % in the next 20 years.
- Yet in many areas of the tropics, there are limits on how far this need to intensify agricultural production can be satisfied.
- Because of the growing populations and the resulting shortage of land, many small subsistence farmers can no longer follow the traditional practice of interposing fallow periods of adequate length (6-10 years) in tropical agriculture, such periods play an important role in restoring the humus content and promoting an accumulation of essential plant nutrients.
- The result is a decrease in the natural fertility of the soil, leading to degradation phenomena which are already apparent in agricultural soils in many regions, e.g. the salinity problem in irrigated regions, the acidification of heavy fertilized soils in West Africa, and the accumulation of detrimental residuals of pesticides all over the tropical world.

- In the short run, yields can be boosted through the use of fertilizers, but most small farmers lack the capital required for this approach.
- Because of the unfavourable soil properties, the mineral fertilizers are not well utilized, which means that the desired long-term increase in yield can only be achieved through the continuous application of fertilizer. This is particularly true for those tropical soils which tend to be subject to leaching of the nutrients and phosphate fixation.

Because of these constraints, the farmers are faced with the urgent task of securing their yields by using available local resources; furthermore, the most appropriate strategies to improve and sustain the fertility of the soils, while at the same time ensuring increased production.

Possible solutions which up to now have not been sufficiently researched is the role of biological measures. Particularly the use of useful micro-organisms and organic matter. Although, most of the biological measures have deep roots into ancient centuries, however, their potential is decreasing in the last decades due to intensive fertilization for maximizing the yields.

During the last few years , several research works world-wide have indicated the important role played by soil biology in sustaining the fertility of tropical and subtropical soils. Recently, a large and growing number of international scientists are actively searching for the combination of factors which can be used to describe the soil fertility or soil quality. Soil biology is a cornerstone in developing these indices and yet the understanding of underground biological system is in the early stages of maturity as a scientific discipline.

The biological system present in the soil ranges from the minute to the large mammals, e.g., gophers and moles. One can easily see the effect of large burrowers left by some of the mammals. The effects of the microscopic organisms like bacteria and fungi are less dramatic but they are the key to improving the soil fertility.

The role and potential of useful micro-organisms for plant nutrition in tropical and subtropical soils

The humid- and sub-humid tropics are characterized by climatic factors (near constancy of temperature and humidity) which are responsible for high plant biomass productivity throughout the year. The semiarid and arid tropics are the dry areas of meagre and undependable rainfall, in which the average precipitation often is lower than the potential evapotranspiration. In the semiarid zone the amounts of rain, are, more or less, sufficient for certain types of crops, requesting special management techniques. In arid zones, arable crop production is not possible without irrigation. With the explosive increase in world population, there is increasing pressure on dry lands which constitute fully one-third of land area of the globe.
The arid parts of a great number of countries are now usually vast empty areas. A large proportion is desert, and its contribution to food production is minimal. On the other hand, where water is available (oases) small areas produce a large variety of crops with excellent yields -an indication of the potential of these regions. A limiting factor of irrigated soils in arid areas is salinity which can drastically reduce productivity.

In general, most soils of the tropics and subtropics lacking in significant available nutrients, and phosphorus and nitrogen are considered to be the most deficient plant nutrients. Micro-organisms, the unseen citizens of the soil, control soil productivity by recycling the carbon, nitrogen and other mineral containing compounds in plant and animal residues to form once again available for use by plants. The soil microbiological community also regulates the production and destruction of environmental pollutants and biologically toxic elements and compounds.
In this context some research activities of our institute will be presented to demonstrate the key role of the useful soil micro-organisms in improving the phosphorus and nitrogen supply to plants in tropical and subtropical soils, such as the (vesicular-) arbuscular mycorrhizal fungi ((V)AMF), the phosphate-solubilizing bacteria, the nitrogen-fixing symbiotic, associative and free-living bacteria, and the Azolla/Anabaena-symbiosis in flooded rice.

Main fields of research on the use of biological measures at the „Institute for Crop and Animal Production in the Tropics“, Goettingen, Germany

A- Phosphorus nutrition of plants

I- (Vesicular-) arbuscular mycorrhiza, (V)AM
Mycorrhiza is the symbiosis between soil fungi and most higher plants. The (vesicular) arbuscular mycorrhizal fungi ((V)AMF) are obligate symbionts and cannot be propagated in axenic pure culture. The growth-promoting effect of the (V)AM is based primarily on the improved uptake of nutrients, especially of phosphorus by mycorrhizal roots, particularly on poor, marginal and P-fixing soils, which frequently occur in the tropics and subtropics.

A huge number of experiments was carried out under simulated (in the greenhouse) and natural growth conditions of the tropics and subtropics

Eco-physiological studies:
- Great number of species and strains (isolates) of (V)AMF,
- Plant species (approximately 40 tropical and subtropical plant species) and host specificity
- Soil type (acid to alkaline, soil-pH),
- Fertilization with phosphates of different solubility (soluble and hardly soluble phosphates, e.g. rock phosphates),
- Soil temperature,
- Soil water-regime,
- Soil organic matter,
- Soil salinity,
- Soil content of Al and the heavy metals Fe, Mn, Zn, Cu, Pb and Cd, and
- Atmospheric factors: light intensity (= insolation) and day-length (photoperiodism), were investigated.

Mechanisms of P uptake by mycorrhizal plants:
Investigations on „How does the (V)AM improve the P supply to plants?“, the role of organic and chelating acids and phosphatases, and the role and quantification of the external mycelium.

Taxonomy:
Isolation, propagation and identification of wide spectrum of species and strains of (V)AM fungi; our institute disposes the greatest collection of these fungi in Europe.

Practical application:
Production of inocula and their application techniques. The utilization of (V)AM in monocultures and mixed cropping systems of crops of different families (*Gramineae*, *Leguminosae*, *Solanaceae*, *Compositae* ....).

Genetic transfer of mycorrhizal efficiency:
The possibility of transferring the property „efficiency of mycorrhiza to improve plant growth by improving P uptake of mycorrhizal roots“ by cross-breeding between plant varieties of different mycorrhizal efficiencies, and the breeding of nutrient efficient varieties (mainly of wheat and sorghum), to increase the production potential of these plants particularly on poor, marginal and P-fixing soils (calcareous and acid soils of the tropics).

Contribution of (V)AM to growth of micro-propagated crops:
Over the past two decades the use of *in vitro* micro-propagation as a technique for the multiplication of several plants has increased rapidly. The main problem of the *in vitro* micro-propagation is the weaning stage for plantlets after the tissue culture. In this stage plants are subjected to severe environmental stress due to poor root, shoot and cuticular formation. This results in an extended weaning stage which is often accompanied by high losses in plantlets and large quantities of chemical inputs in form of fertilizers and pesticides. Several measures such as humidity tents, anti-transpirants, additional light and CO_2 enrichment have all been employed to increase survival rates but with only limited success.
Over the last few years it has been demonstrated that with (V)AM as a biological measure can result in growth enhancement of a wide range of micro-propagated plants especially of those difficult-to-root spices. Under natural conditions, plants are normally colonized with (V)AMF and thus are mycorrhizal. In the *in vitro* micro-propagation, (V)AMF, as with all other micro-organisms, are removed. Furthermore, substrates used in the post *vitro* stages of the micro-propagation technique are normally treated in order to remove potential pathogens which at the same time removes the beneficial (V)AMF. The micro-propagated plantlets will not have the benefits of the symbiosis and only by re-introduction of the (V)AMF will the benefits be acquired.
The savings of energy and chemical inputs due to significantly shorter production cycles and the increases in survival and uniformity of produced plants as a result of inoculation are a major incentive to introduce (V)AM in such techniques, as investigations of our institute have demonstrated with oil palm. Taking these benefits of mycorrhiza into consideration it is likely that in the future inoculation with (V)AMF, will be an integral biological measure of most micro-propagation systems, but a carefully selected and produced (V)AMF inoculum based on relevant research is urgent needed.

II- Phosphate-solubilizing bacteria:
The utilization of *Bacillus megaterium* var. *phosphaticum*, *Pseudomonas fluorescens*, *Pseudomonas putida*, *Pseudomonas stukerii*, and *Citrobacter freundii* alone and combined, or in combination with (V)AMF, was investigated.

B- Nitrogen nutrition of plants

The utilization of the „Biological Nitrogen Fixation, BNF“, by *Rhizobium* and *Bradyrhizobium* bacteria with legumes, and associative and free-living bacteria (*Azospirillium*, *Azotobacter*, *Beijerinkia* and *Derxia)* with gramineous crops (cereals and millets), was tested.

I- Interactions between N_2-fixing bacteria, (V)AM mycorrhizal fungi, and phosphate-solubilizing bacteria

The growth and the P and N uptake of several tropical plant species could be improved by the inoculation with various combinations of these effective (useful) microorganisms (EM).

II- Azolla/Anabaena-Symbiosis in flooded rice

Generally, the most effective source of fixed N_2 is the *Azolla-Anabaena* complex. Known additional benefits derived from *Azolla* intercropping are weed control, water saving and temperature regulation. These benefits were recognized centuries ago by Chinese and Vietnamese farmers.

Integrated soil fertility management is essential if soil productivity is to be improved or sustained. With security in rice production assured through intensification, many scientists, policy makers and farmers are rethinking the long term approach to food security, leading to crop diversification and integrated soil fertility management practices.

The problem is how to integrate the traditional practices of the utilization of *Azolla* fern in wetland rice with modern technologies such as fertilizer use, without loosing the benefits of the BNF by this symbiosis.

Information from literature indicates that the Azolla-rice systems are capable of increasing by an average of 20%. An additional 20% can be gained by combining *Azolla* (5-6t/ha) with an application of 30 kg/ha of mineral N. The results of our greenhouse experiments showed that *Azolla* is capable of greatly reducing the losses of ammonia through volatilization, which often may reach 30-40% of the applied N (mostly in form of urea), largely by preventing the increase in pH which observed in the absence of *Azolla* as a result of algal activity. This benefit far outweighed any possible competition for the applied N and may be as important as the contribution of N to the soil/plant system from *Azolla* through its symbiosis with *Anabaena*.

Conclusions and outlook

It is increasingly evident that declining soil fertility is the most widespread and dominant limitation on yields and sustainability of cropping systems. Technologies that can be used to sustain soil fertility are still relatively scarce, especially for smallholders. If researchers and farmers do not make a more vigorous attempts to address the extensive decline in soil fertility, the productivity of the farming systems will fail to increase. The following propositions of main criteria should be considered:

- Some general features of the above mentioned biological measures are known, but their role in sustaining soil productivity under stress growth conditions such as those in humid or dry regions has not been studied effectively,
- It is very important to develop improved techniques for propagation of the obligate symbiotic (V)AM fungi and inoculation with introduced highly efficient fungal spieces and/or strains, and guide-lines for predicting cost effectiveness of inoculation with single or mixed fungi,

- Many kinds of interactions are still unknown in the rhizo-/mycorrhizosphere for different ecosystems. Mycorrhizal fungi are but a part of the microbiological community in the soil and must be considered in this context. Thus, adapted cultivation systems and crop rotations have to be developed concerning legumes, cereals and other non-legumes in sole and mixed cropping,
- For minimizing the inputs in form of chemical fertilization and pest control, maximizing the benefits of inoculations with (V)AM fungi alone or in combinations with other useful soil micro-organisms such as N_2-fixing bacteria and/or phosphate-solubilizing bacteria (bio-fertilizers) is urgent needed,
- Close co-ordinations between soil biologists/microbiologists, plant breeders, agronomists, soil reclamation specialists, producers and consumers of inocula and extension service stations is of great importance for making full use of the biological measures in practice,
- Biological fertility and sustainability depend by far on soil organic matter which is often used as index of soil fertility; adapted crop rotation help in addition of organic matter in the soil,
- As mentioned above, most of the biological measures have deep roots into ancient centuries, mainly the use of different kinds of organic matter as store and/or resource of most biological components; nowadays the benefits of these measures must be precised and their utilization should be adapted to the biotic and abiotic stress conditions of the tropics and subtropics.

„ Building on the past for a better future“

The Institute for „Crop and Animal production in the tropics“, in Goettingen, is engaged in several projects for improving the productivity of the poor marginal soils frequently found in the humid and semiarid/arid tropics, by using these biological measures as „bio-fertilizer“ and/or a tool of sustainable agricultural systems.