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Fertility management of the soil-rhizosphere system

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ABSTRACT

Very small proportion of rhizosphere soil is of critical importance for plant growth and health. The soil-rhizosphere zones occupied less than 0.5 to 20 % volume of the upper surface soil in a annual crops or fruit tree. Designing sustainable management practices that focus on rhizosphere soil is more efficient and cost-effective for improving crop productivity with fewer agrochemical inputs. The innovative Starter Solution Technology (SST) for applying nutrients directly to the soil-rhizosphere system. The SST reduces fertilizer application, increases crops yields, decreases fertilizer residues in the soil and is simple to apply. Other practices for managing the fertility of rhizosphere soil, such as supplying nutrients through drip irrigation, applying organic fertilizers and biocharcoals to increase soil-buffering capacity and localized amendment as strategies for problem soils are also discussed. All of the proposed management practices can be easily adopted by Asian farmers.

Key words : Soil rhizosphere, Fertility management, Plant growth

INTRODUCTION

The rhizosphere concept was first introduced by Hiltner in 1904 to describe the narrow zone of soil surrounding the roots where microbe populations are stimulated by root activities. It thus distinguishes from the "bulk" soil, which is not influenced directly by growing roots. The original concept has now been extended to include the soil surrounding a root in which physical, chemical and biological properties have been changed by root growth and activity (McCully, 2005).

By definition, the rhizosphere is the volume of a thin layer of soil immediately surrounding plant roots that is an extremely important and active area for root activity and metabolism. Important physiological processes in this zone are the uptake of mineral nutrients and microbial activity enhanced by root exudates; it is profoundly different from the bulk soil.

The extent of the rhizosphere's share in the topsoil varies with genotype, nutritional status of the plants, soil conditions and factors that influence root growth. For an annual crop or fruit tree, the rhizosphere soil can constitute between 0.5 to 20% of the topsoil. Welbank *et al.* (1974) reported that the roots of winter wheat occupied about one per cent of the volume of the upper 15 cm of soil. Other observations show that the volume of root systems is seldom more than five per cent of the surrounding soil. Knowing the differences in the extent of rhizosphere soil is important for determining the best fertilization practices (Römheld and Neumann, 2005).

However, major vegetable tap and fibre roots are distributed in the 15 cm3 of soils surrounding the core of the taproot. Which occupies 5 to 7% volume of surface soil (Fig. 1). Fertility management on this small soil zone is more costeffective than management on whole bulk soil(Ma and Palada, 2006).

Components that affect nutrient availability in the soil-rhizosphere system :

Microbial activities and the biological control of pathogens in the soil-rhizosphere system have been extensively studied. However, less attention has been

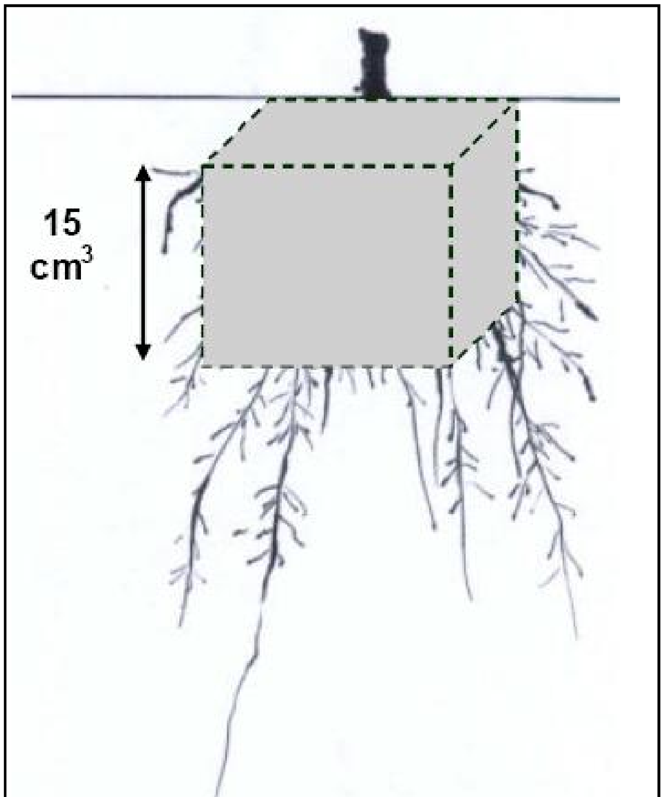

Fig. 1 : Proposed soil- rhizosphere zone for nutrient supply and fertility management

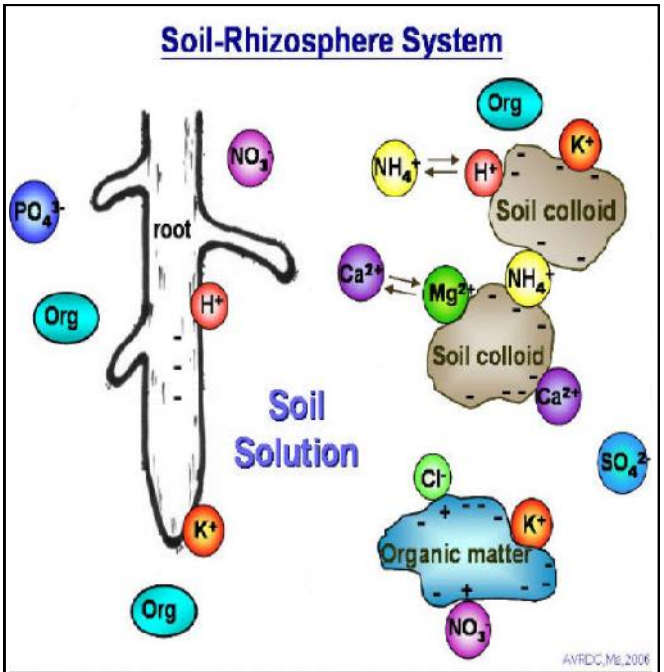

Fig. 2 : Components that relate to nutrient availability in the soil-rhizosphere system

focused on fertility management in the soil-rhizosphere zone due to possible fertilizer burning when fertilizers are applied too close to roots. Due to soil buffering capacity and micro-organism function, roots are actually more tolerant to drastic changes of conditions in the rhizosphere than one would expect. Fig. 2 illustrates the components that govern nutrient availability in a soil-rhizosphere system, *i.e.* plant roots, soil colloid particles, organic matter, soil solution, micro-organisms and nutrient ions. This paper focuses on practices that can improve soil-fertility components, such as increased nutrient gradient in soil solution, increased soil organic matter or carbon, increased buffering capacity of soils and adjustments that influence nutrient form and availability such as soil pH.

The Starter Solution Technology (SST) is a recently developed practice for managing soil fertility near the soil-rhizosphere zone. Other existing practices for managing soil-fertility components near the soil-rhizosphere system and that can be used by farmers in developing countries.

Importance of soil-rhizosphere processes and their relation to plant growth :

Changes in the soil-rhizosphere system

Many researchers have documented drastic changes in rhizosphere conditions, such as pH, redox potential, microbial activity and nutrient availability fluxes (Römheld and Neumann, 2005). Changes in pH of 2 to 3 units are common within the rhizosphere of distinct root zones and directly affect nutrient availability for root uptake. The magnitude of pH changes in the rhizosphere will depend on plant genotype, nutritional status and soil-buffering capacity (Neumann and Römheld, 2002). Farmers can also manipulate rhizosphere pH by applying different forms of N fertilizer, *i.e.* applying nitrate N to promote pH increase and ammonium N to decrease rhizosphere pH, thus affecting the uptake of different nutrients.

Similarly, the redox potential of soils can also vary over a wide range due to release of root exudates. Changes in redox potential in the rhizosphere may result in Mn toxicity or deficiency in certain crops. Differences in the microbial population found in the rhizosphere can vary 10 to 100-fold compared to the bulk soil because of the release of root exudates and their composition. Another change in the rhizosphere is the accumulation or depletion of mineral nutrients, depending on the solubility of a given nutrient in soil solution and plant uptake. These changes will have significant effects on plant access to water, especially under drought conditions. All of the different rhizosphere processes can have complex interactions. When seeking effective rhizosphere management strategies, farmers need to take into account all rhizosphere changes (Römheld and Neumann, 2006).

Importance of soil-rhizosphere processes for plant growth :

The rhizosphere acts as a nexus for plant, soil and microbial interaction. Rhizosphere processes are important for plant growth as they improve root growth, enhance nutrient acquisition and protect crops against pests and pathogens (Römheld and Neumann, 2006).

In natural and alkaline soils, rhizosphere acidification induced by NH4-N supply, can increase acid-soluble Ca phosphate and micronutrient availability. In acid soils, however, rhizosphere acidification will not increase P availability. In contrast, rhizosphere alkalinization, as found in field-grown millet and some legumes, can enhance P availability by improved microbial P mineralization (Neumann and Römheld, 2002). Rhizosphere acidification can also efficiently enhance K release either by desorption or by solubilization of K sources with low solubility. All these processes demonstrate the importance of plant root-induced mobilization in the rhizosphere to enhance the nutrient concentration in the rhizosphere-soil solution.

It is evident that the availability of Mn in the rhizosphere, as well as of Cu and B plays a decisive role in plant health. Management strategies need to account for enhanced acquisition of these nutrients.

The small area of the rhizosphere soil is an extremely important and active site for nutrient bioavailability, root growth and disease suppression. Best management practices for soil-rhizosphere systems should be based on the knowledge of rhizosphere processes to achieve desired improvements in plant growth and health with less agrochemical (fertilizers and pesticides) inputs. There is great potential to improve fertility management through this new approach that focuses on the soil-rhizosphere system.

Practices for direct supply of nutrients to the soil-rhizosphere system :

Application of the Starter Solution Technology (SST) for efficient vegetable production and fertilizer use

Background and rationale :

For achieving rapid fertilizer responses, farmers tend to over apply both organic and inorganic fertilizers in intensive farming systems. Excessive applications of fertilizer cause environmental pollution and human health hazards. Improper fertilizer management also results in nutrient imbalance in soils and degrades land in many countries. Asian farmers urgently need judicious fertilization strategies that can improve the efficiency of nutrient uptake by plants and minimize environmental risks.

The SST supplies readily available nutrients directly to the soil-rhizosphere system. Small amounts of very concentrated inorganic fertilizer solution are applied to rhizosphere soils immediately after transplanting; they build up high nutrient gradients in the soil solution providing young plants with readily available nutrients before their root systems are well established, thus, enhancing initial growth. Healthy young plants can be more tolerant to environmental stress and increase their early yield, which means more income for farmers.

When a person is sick or injured, the doctor often injects a vitamin supplement because this is the most effective way of supplementing vitamins. Similarly, when a plant's roots are damaged by transplanting, natural trauma or heavy rain, it is crucial to receive an instant, readily available nutrient to facilitate recovery. Based on this concept, researchers at AVRDC developed the Starter Solution Technology (SST) for enhancing early growth and overall yields of the vegetable crops tested *viz., inter alia,* cucumber, tomato, chili pepper, cabbage, lettuce (Ma and Palada, 2006).

Application practices :

The concentration of the starter solution must be based on soil fertility, soil-buffering capacity, plant species and varieties. The soil at the AVRDC field was silty loam with about 1.5% organic matter and 8- 10 meq/100g soil CEC. In general, the lower the soil fertility, the better the effects of the starter solution. For first application of SST, it is necessary to make a preliminary test by transplanting several plants in the field and applying different concentrations of starter solution to each plant, followed by irrigation. If the plants do not wilt or die after one to two days this indicates that the concentration of the starter solution is suitable for the plants.

The booster effect of the SST is best when the soil is dry before application. Due to dryness on the soil surface, the nutrient solution can be adsorbed on the soil surface for some time. On the other hand, the booster effect of the SST is best when it is applied immediately after transplanting and followed by furrow irrigation from the bottom to the top of the beds. The SST can also be applied at later critical stages, such as at head initiation or fruit-setting stages, to replace some inorganic or organic solid fertilizers. When applying the SST, the total amounts of solid fertilizers should be reduced, otherwise, the effects of the SST at later growing stages may not be obvious.

In conclusion, the positive effects of starter solution application on initial plant growth were evident. Later in the cropping season, the effects of SST used as a side-dressing on yield varied depending on the vegetable, timing of the side-dressing and other supplemental fertilizers. Balanced fertilization practices based on SST in combination with organic and inorganic nutrient sources can lead to increased fertilizer efficiency, higher profits for farmers and reduced risks of environmental pollution. This technology is very easy to apply and modify for different vegetables; it is a low input, soil-based approach, which may also be applicable to situations wherever excessive fertilizer use prevails or where fertilizers are rather costly for farmers — moreover, leaching can be reduced (Ma and Palada, 2006).

Drip irrigation for managing nutrients and water in the soil-rhizosphere system :

Global climatic changes result in uneven distribution of water — either drought or floods — in many regions of the world. Water is increasingly becoming a scarce resource even in the humid tropics. The situation is worse during the dry season in most rain-fed areas. Thus, there is a need to develop technologies that promote efficient use of water and fertilizers in vegetable production. Drip irrigation formerly was a labour-saving practice. It is now a mandatory technology for managing water and nutrients in the soil-rhizosphere system.

High volumes of water application through flooding or furrow irrigation are not efficient. Excessive fertilizer application with furrow irrigation leads to environmental pollution and degradation due to leaching of nutrients into underground water. Direct supply of nutrients through drip irrigation in the soil-rhizosphere system appears to be a low-cost, efficient and affordable technology. Compared to furrow irrigation, drip irrigation uses less water, improves the yield and quality of vegetables, promotes efficient use of fertilizers, reduces the spread of soil-borne diseases and decreases the risk of groundwater contamination. A low-cost drip irrigation system developed by the *International Development Enterprises* (IDE, India) uses locally available materials. It is easy to operate, repair and maintain. The customized systems are available in user-friendly kit forms. They are poly tube drip and easy drip, using micro tubes as emitters, and are meant for small farmland (20-1,000m^2). They also come in two types: a) micro-sprinkler kit and b) mini-sprinkler kit (Postel *et al.,* 2003).

Practices for enhancing soil-buffering capacity in the soil-rhizosphere system :

It is well known that applications of organic fertilizers can supply nutrients to plants and at the same time increase soil organic matter, which will increase the nutrient-holding capacity of a soil. Traditionally, organic fertilizers are broadcast on the surface soil and incorporated uniformly into the soil. However, organic fertilizers decompose very quickly under tropical conditions. The nutrients released from organic fertilizers are also subjected to leaching if the crops do not take them up in time. Application of organic fertilizers or organic amendments in the soil-rhizosphere system may concentrate nutrient ingredients in the soil solution and increase retention time of organic matter in rhizosphere soil, thus enhancing soil fertility in the soil-rhizosphere system.

Lehmann *et al.* (2006) has proposed a new approach to carbon sequestration in global ecosystems through the application of biomass-derived charcoal (bio-charcoal) onto soil. Biocharcoal such as burnt rice husk, can act as a soil conditioner enhancing plant growth by supplying and, more importantly, retaining nutrients and improving soil physical and biological properties (Lehmann and Rondon, 2006). Biocharcoal is more resistant to decomposition and can remain in the soil for many years. Higher nutrient retention and nutrient availability were found after charcoal additions to soil; this was related to higher exchange capacity, surface area and direct nutrient addition from charcoal (Glaser *et al.* 2002).

Not all agricultural waste materials are suitable for producing biocharcoal with the exception of rice husks (FFTC, 2001), which have high concentrations of silica entrapping C during combustion. The rice husk ash also contains other mineral nutrients such as Ca, Mg, Fe, Mn and K. Application of biocharcoal is a new technology to ameliorate components as soil colloid particles and increase soil fertility in the soil-rhizosphere system.

Practices to manage the soil-rhizosphere system as strategies for the amendment of problem soils :

Localized amendment concept :

In considering the rhizosphere, most researchers focus their attention on micro-organisms. Many management technologies that focus on the soil-rhizosphere system have been adapted worldwide. However, the concept of managing the small but critical soil-rhizosphere system has not been promoted extensively. When soil degradation expands, the amendment of problem soils based on the soil-rhizosphere system provides new ways to reduce cost and to decelerate deterioration. The amendment of problem soils can be achieved by amending the rhizosphere soils first. Examples are given hereunder:

- Acid soils: liming the acid soils in rhizosphere soils only;

- Alkaline soils: adding sulphur powder to soils near the soil-rhizosphere zone;

- Sandy soils: apply organic fertilizers in rhizosphere soils to retain nutrients and water close to the roots;

- Highly weathered soils: apply lime and phosphorus fertilizers in rhizosphere soils;

- Saline soils: leach away salts near rhizosphere soils by drip irrigation or other tools;

- Sodic soils: apply gypsum near rhizosphere soils to exchange Na with Ca;

- Heavy textured soils: incorporate sand or slowly decomposed residues in rhizosphere soils to improve drainage and aeration.

Other management technology :

Apply high bed or high pot technology to avoid

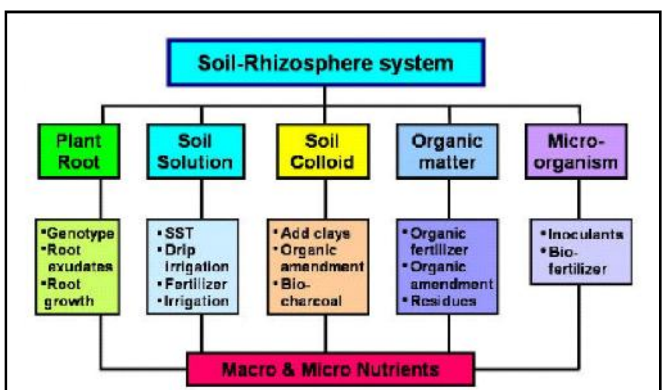

Fig. 3 : Practices for managing soil fertility in the soil-rhizosphere system

flooding near rhizosphere soils; shaping special beds for saline soils to reduce salt accumulation on bed surfaces caused by evaporation are all practices that focus on water management in the soil-rhizosphere system.

Conclusion:

Fertility-related components and practices to manage or ameliorate these components are summarized in Fig. 3. As soil degradation in the world is expanding, the concepts and practices for managing rhizosphere soils deserve more attention and promotion as approaches toward more sustainable agriculture.

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