Modifying Soil to Improve Crop Productivity

By Luis I. Prochnow and Heitor Cantarella

The majority of the world's agricultural lands require some degree of soil improvement in order to support sustained productivity.

Soil Availability in the World

About 12% of the world's land area—around 1.5 billion ha—is currently used for crop production. Although reasonable amounts of land are still potentially suitable for crop production, much of it is covered by forests, protected for environmental reasons, or used for urban settlements (FAO, 2013). As a direct consequence of increasing world population, arable land per person is decreasing rapidly. It is projected that the world will only have 0.20 ha per person in 2050, as opposed to having 0.45 in 1960. This arable land "crunch" is much more of a developing world issue where the expected availability will be 0.15 ha per person versus 0.45 ha in the developed world (Bruinsma, 2009). As such, the increasing demand for agricultural products will put pressures on expanding into existing pasturelands (3.4 billion ha) or marginal, low productivity grasslands, savannas, and shrublands (1.1 billion ha, Cai et al., 2011). However, most of these areas have at least one suboptimal soil condition that would need to be addressed. All of these points suggest the need to increase the productivity of food, feed, fiber, and energy upon our global inventory of arable lands. This will only be possible through the advancement in technologies focused on integrating the proper management of all conditions that influence crop growth.

Soil Conditions that Affect Crop Growth

Several soil conditions influence crop growth and final yield. The list of factors considered to be most important includes: soil pH, nutrient availability, water status, oxygen availability, soil temperature, salinity, and soil permeability (**Figure 1**). Plants vary in requirements for each of these conditions. However, high and economic yields are only obtained when they are all near an optimum. For example, sustained productivity cannot be achieved in a soil with good nutrient balance if poor soil permeability is restricting plant root growth.

As we strive to meet the challenge of improved yields per unit of managed area, it is important to understand both where and why productivity can lag. The concept of the yield gap is defined by van Ittersum and Cassman (2013) as the difference between the yield obtained under optimum (or best) management and the average yield achieved by local farmers (**Figure 2**). Best management practices (BMPs) are our tools for modifying the condition of soil, ensuring good plant growth, and reducing the size of any existing yield gap. These practices are most effective and sustainable if they are supported by universal scientific principles, and are adapted to the social, economic and environmental contexts in which they are used.

It should be recognized that some problems in soil are relatively easy to manage, while others are influenced only indirectly. Soil pH, nutrient availability, and water availability are examples of soil conditions that can be more easily modified.

Abbreviations and notes: N = nitrogen; Ca = calcium; Al = aluminum.

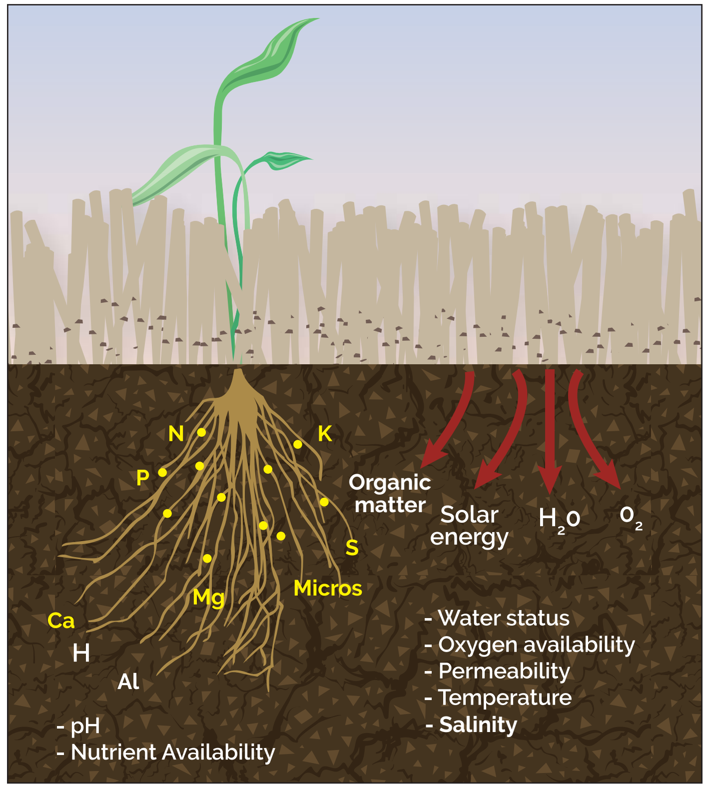

Figure 1. Plant productivity is partially a reflection of soil management, which should create the conditions necessary to optimize all soil factors considered most influential for plant growth.

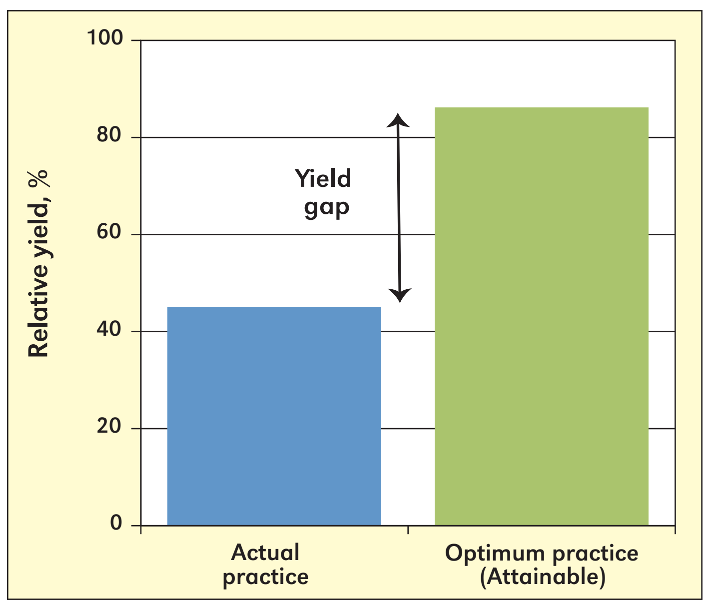

Figure 2. The gap between actual farm yields and what is considered optimum, or attainable, is primarily a reflection of the development and adoption of best management practices.

Soil pH

Excess soil acidity is a major problem in large areas of the globe, especially in highly weathered soils of the tropics, in low-yielding pasture lands, and marginal soils. The capacity of plants to tolerate soil acidity varies, but most plants grow better under slightly acidic soil conditions (pH from 5.5 to 6.5). For example, rice plants grow well in soil pH as low as 4.8; maize typically does best between 6.0 to 6.5; alfalfa grows better if soil pH is near 7.0. Even in highly productive soils, acidification may take place due to leaching of base cations and use of N fertilizers. Monitoring soil acidity with periodic soil analysis and use of lime will prevent the loss of soil quality associated with acidification, especially at depth where soil properties are harder to correct. Liming also can help to bring more soils into high-yielding agricultural production. In some cases, gypsum may be used to alleviate the problems of excess Al^{3+} and lack of Ca^{2+} in the subsoil, thus allowing deep root growth, which is important for the absorption of water and nutrients below the surface soil layers.

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Application of lime at a large scale using commercial equipment.

Nutrient availability

Inadequate chemical properties associated with nutrient availability can be modified to improve biomass production. A good and consistent supply of nutrients from the soil is fundamental for adequate plant production and it can be evaluated and managed by the use of different tools. Calibrated soil analysis and nutrient recommendations based on yield response curves under local conditions and with consideration of nutrient experts, is an effective means of securing high yields, preventing soil degradation due to unbalanced nutrient input, and making good use of lands with limiting fertility. Proper diagnostics of nutrient availability creates site-specific fertilizer recommendations, reduces costs, and avoids excess nutrient accumulation and its undesirable environmental impacts. Other technologies that can help the understanding of soil nutrient availability include diagnostics for interpreting visual symptoms of deficiency or toxicity, plant tissue analysis, and local agronomic experimentation. In countries where these techniques are not available, or feasible, other tools should be developed to help understand soil nutrient availability and the 4Rs of Nutrient Stewardship (i.e, right source, right rate, right time, and right place) at a field-scale. A successful example is the development of the Nutrient Expert® decision support tool, which relies on the combined use of nutrient omission field trials and nutrient accumulation modeling to ultimately determine crop-specific nutrient uptake requirements, and provide a farmer with a regionalized fertilizer recommendation (Pampolino et al., 2012).

Water status

Soil water availability is a factor of increasing concern for most crop production systems. The selection of well-adapted, water-efficient crop varieties is critical to achieving the best use of soil water. Efficient field tools and sophisticated instrumentation techniques needed to monitor soil moisture and crop demand for water—both in rainfed and irrigated systems—are often readily accessible in many parts of the world affected by drought. Adaptive management practices (e.g., conservation tillage, cover cropping) are needed to promote optimal soil physical, chemical and biological properties, stimulate deep rooting within the soil profile, and lessen the impact of reduced water availability.

Practices to Improve Soil Conditions

Soil compaction, salinization, erosion, crusting, loss of soil organic matter and soil microbiological diversity can be corrected with several restorative agronomic practices. In some cases, sub-soiling and other mechanical operations and equipment (i.e., use of adequate tires in the field) can directly minimize or correct problems of compaction and deficient soil aeration. Many adaptive practices are adopted with the short-term goal of improving the cropping system first and the longer-term goal of improving the underlying soil condition over time. Two clear examples of such practices are no-till and region-specific crop rotation.

No-till

No-till (also called zero tillage or conservation tillage) is a way of growing crops or pasture from year-to-year with minimal physical soil disturbance. It usually promotes an increase in organic matter retention, modifies macro and micro soil porosity, and also influences the cycling of nutrients. In many

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Use of minimum tillage will reduce the potential for erosion, but more soil acidifying processes (like crop residue decomposition, nitrification of N fertilizers, etc.) occur at the soil surface.

Photo credits: Emerson Borghi (A and B) and Rogério Soratto (C and D)

Figure 3. Examples of brachiaria grass used with corn – seen at different stages: (A) before harvest, (B) at harvest, (C) soon after harvest, and (D) some weeks after harvest.

regions it can reduce or eliminate soil erosion. As a result of such modifications, no-till can positively influence soil conditions such as aeration, heat and soil permeability. It may also influence nutrient and water availability, all of these leading to better conditions for plant growth.

Crop rotation

Region-specific crop rotation (i.e., cropping sequence adapted to the region) can also have a positive influence on soil conditions. Creative alternatives, such as the Brazilian practice of using forage grasses in rotation with cereal crops, can generate clear benefits for soil conditions and nutrient availability (**Figure 3**). The rotation of crops with different root architecture and physiology help to access nutrients in different layers and chemical forms in the soil. Longer root extension and root exudate release increase the capacity to access forms of nutrients not easily available in traditional cereal crop systems (Crusciol et al., 2010).

Conclusion

Good soil husbandry is essential to improve and maintain soil quality and to increase crop productivity. Nutrient management, associated with other agronomic measures, is central among these practices, especially to modify soils with permanent or temporary limiting conditions, in order to incorporate them to the agricultural system. The literature is dense in offering knowledge so the soil can be modified as per best management practices, which should be always adapted to local conditions. BC

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