Review

Soil science in the understanding of the security of food systems for health

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Soil is a basic natural resource for food production, the vast majority of food we consume is either directly or indirectly derived from soil. Soil quality determines the quantity (calories) and quality (nutritional value and safety) of the foods grown. Protecting the soil's physical, chemical and biological integrity is therefore of vital importance in safeguarding global food security. Soil science, as a discipline, will contribute to new knowledge related to soil quality and its sustainable management. However, soil scientists are not alone in securing the global food production system, instead they shall work with environmental engineers, agronomists, nutritionists, animal scientists and social scientists in developing integrative approaches to soil conservation, material cycling and environmental protection.

Key Words: biodiversity, contamination, food security, nutrition, soil quality

INTRODUCTION

Food security has been fundamental for poverty alleviation in less developed countries and the long-term sustainability the world at large. According to United Nations Food and Agriculture Organization (FAO), food security is defined as "when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life". With this definition, it implies that the food delivery system should not only supply enough food to members of the society, but also ensure that the foods contain sufficient nutrients and minimal toxicants to meet health requirements. Despite efforts at all levels of the globe, food security will remain a worldwide concern for the next 50 years and beyond.[1] Recently FAO announced that world hunger is projected to reach a historic high in 2009 with 1.02 billion people going hungry every day, indicating that food insecurity remains a global issue. While it has been suggested that both bio-energy production and the global economic crisis have contributed to the current food insecurity situation, food insecurity is likely to increase under climate change, unless early warning systems and development programs are used more effectively.[2]

Although the FAO definition of security also includes food quality, insufficiency of micronutrients essential for human development and health attracts less attention, albeit that it has been an issue affecting a large percentage of the global population.[3] Some estimates have indicated that over 3 billion people in the world are at risk of micronutrient malnutrition, and that number is likely increasing.[3] Therefore it is clear that micronutrient deficiency and/or the toxicant accumulation are further hampering food security in different parts of the world.

From the above brief discussion, it is clear that ensuring food security is a multi-faceted goal, and requires holistic approaches towards harmonization among land use, environmental sustainability, economic benefits and human health. Although technological advancements, such as irrigation and new improved cultivars, can enhance food security, soil as the fundamental resource remains the core of the issue. Soil quality (and hence nutrients) can play a significant role in alleviating the negative impacts from other societal problems. There are roughly four aspects of soil quality that have often been discussed in relation to food security in the literature; these include soil erosion, soil biological properties, nutrient balance and soil pollution.

SOIL EROSION

Soil loss due to erosion is a major threat to food security. Human-induced soil erosion has been known for a long time. For example, in the loess plateau in China, soil erosion increased rapidly in the Tang Dynasty[4] echoing rapid economic expansion during that period. Soil erosion often removes the finer and more fertile fraction of the soil, and it is clearly a big threat to sustainable agricultural production, thus to food security.[5] Many experimental studies have explicitly demonstrated that for most tropical and

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many temperate soils the relationship between crop yield and cumulative soil loss is a curvilinear and negative exponential one.[5] At the technological level, developing best farming practices (BFP) seems the key to curbing soil erosion, as BFP will integrate many appropriate technologies available under different socio-economic conditions. However, it should be noted that both the development and adoption of BFP require substantial economic investment and governance at all levels.

NUTRIENT DEPLETION OR ENRICHMENT?

The chemical composition of plant tissues requires a certain stoicheiometry between carbon and essential nutrients, which results in the removal of nutrients at harvest, such as nitrogen, phosphorus and potassium from the soil. If not replenished, repeated cropping will lead to the depletion of soil nutrients, this is particularly true in poverty stricken areas, such as sub-Saharan Africa,[6] where accessing to chemical fertilizers is often a problem. Continuous nutrient depletion is hampering food security by yield decline, and for subsistence farmers, yield decline means poor income, leading to a somewhat vicious cycle of poverty and food insecurity.

Equally problematic is the enrichment of nutrients in intensive agricultural production systems, such as in China.[7] It was estimated that in the maize production system in northern China, surplus of nitrogen and phosphorus reach 227 and 53 kg ha^{-1} $year^{-1}$, respectively.[8] The immediate impact of nutrient enrichment in agroecosystems is the damage that it imposes on the environment, both air and water, as well as the economic cost.

Both scenarios presented above are not sustainable in terms of the environment and resource management. In any case, to support the growing global nutrient input to agroecosystems is inevitable, but unfortunately the supply of mineral nutrients, such as phosphorus and potassium is not unlimited. Taking phosphorus as an example, under the current rate of exploration it has been estimated that on world average rock phosphate will be depleted in about 50-100 years.[9] In the same time, rapid urbanization is increasingly directing the nutrient (nitrogen and phosphorus in particular) flow into cities in the form of food, and these nutrients will eventually end up in sewage sludge, domestic garbage and reclaimed water. However, this is not the case in the agricultural society, in which nutrients are largely recycled through returning human and animal wastes back to the field. Although it is not possible and unnecessary for us to de-urbanize our society, technologies and policies make the recovery of major nutrients from sewage sludge seem essential for food security in long term.

SOIL IS ALIVE

The importance of maintaining the soil's biological properties for food security has also attracted wide attention in recent years. Soil is perhaps the most remarkable habitat on Earth that is harboring rich biodiversity. Soil biota is responsible for the turnover of organic matter and the transformation of nutrients, such as nitrogen and sulphur, thus is an integral part of soil quality. The role of soil biota in plant growth and hence productivity is now well known.[10] One typical example is the symbiotic association between plants and mycorrhizal fungi, and it has been shown that increasing the diversity of mycorrhizal fungi in soil can enhance plant productivity, quite possibly through improved nutrient acquisition.[11] Another example of the role of soil biota in ensuring food security is biological nitrogen fixation. It has been recently estimated that 50-70 Tg N maybe fixed annually by biological agents in the global agricultural system.[12] Despite the extremely high diversity of the soil microbial community, more recently it has been shown experimentally that soil microbial communities of differing composition are functionally dissimilar,[13] thus managing soil biodiversity seems even more important than previously perceived.

SOIL FOR HEALTHY PEOPLE

We are what we eat. Since what we eat is ultimately derived from soil, our health is heavily influenced by the soil's chemical compositions, particularly trace elements, such as iodine, selenium, zinc and iron. It is well known that iodine deficiency can cause goiter formulation; the first endemic disease attributed to the environment.[14] One typical example is found in Xinjiang, the most distant city from the sea on Earth, where iodine deficiency is still a problem. Aother example is selenium deficiency and the prevalence of Keshin-Beck Disease in certain areas of China. Today, because of the great mobility of people and trading of food between regions/countries, the problem of diseases related to the environment seems less important, and tends to be neglected. However, firstly, one should note that the deficiency of trace elements can occur well before the development of illness and other visible symptoms; secondly, poverty stricken population often have less mobility and are largely reliant on what they can grow locally. Since in most cases, dietary intake is the predominant source of trace elements ingestion in humans, it is important that trace elements in the food supply chain are characterized. We have recently characterized the selenium situation in the global rice supply chain, and we believe that this should be expanded to other elements and other food sources.[15]

In ancient China, people learnt to use seaweed to cure goiter,[14] and in modern society fortified salt or other functional food are widely available to compliment of the deficiency of trace elements in food. However, for a better delivery mechanism, it has been argued that biofortification (i.e., improving trace element density in primary food sources, such as in cereals) is more widely accessible and more cost-effective.[3]

In parallel to trace element deficiency, excessive concentrations of toxic elements in food are confounding the nutritional value of the food and causing health problems. One example would be cadmium contamination in rice and "itai-itai" disease.[14] With rapid industrialization, there seems no end to toxic substances entering the environment, and efforts should be made to ensure that the entry of these toxic substances into our food supply chain is minimized.

CONCLUSIONS

The preeminence of soil as the basic natural resource for food production makes soil science an indispensable discipline in safeguarding global food security. Endeavors in developing new knowledge and soil science-based BFPs will enhance our ability to support food security globally, these endeavors include:

- The development of rapid and reliable monitoring tools for soil and food quality and digital archiving of the monitoring data to assist decision making;
- The development of new soil conservation systems to minimize soil erosion and to protect soil biodiversity;
- Working with environmental engineers to develop sustainable ways of recycling nutrients from wastes;
- The development of integrative and cost-effective ways of enhancing trace elements while minimizing the accumulation of toxic substances in food, through crop breeding, the application of novel fertilizers as well as novel pollution prevention and remediation technologies;

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AUTHOR DISCLOSURES

None.

REFERENCES

1. Rosegrant MW, Cline SA. Global food security: Challenges and policies. Science. 2003;302:1917-9.
2. Brown ME, Funk CC. Food security under climate change. Science. 2008;319:580-1.
3. Welch RM, Graham RD. Breeding for micronutrients in staple food crops from a human nutrition perspective. J Exp Bot. 2004;55:353-64.
4. Ren M, Zhu X. Anthropogenic influences on changes in the sediment load of the Yellow River, China, during the Holocene. Holocene. 1994;4:314-20.
5. Stocking MA. Tropical soils and food security: The next 50 years. Science. 2003;302:1356-9.
6. Drechsel P, Gyiele L, Kunze D, Cofie O. Population density, soil nutrient depletion, and economic growth in sub-Saharan Africa. Ecol Econ. 2001;38:251-8.
7. Ju XT, Xing GX, Chen XP, Zhang SL, Zhang LJ, Liu XJ et al. Reducing environmental risk by improving N management in intensive Chinese agricultural systems. Proc Natl Acad Sci U S A. 2009;109:3041-6.
8. Vitousek PM, Naylor R, Crews T, David MB, Drinkwater LE, Holland E et al. Agriculture. Nutrient imbalances in agricultural development. Science. 2009;324:1519-20.
9. Cordell D, Drangert JO, White S. The story of phosphorus: Global food security and food for thought. Global Environ Chang. 2009;19:292-305.
10. Wardle DA, Bardgett RD, Klironomos JN, Setala H, van der Putten WH, Wall DH. Ecological linkages between aboveground and belowground biota. Science. 2004;304:1629-33.
11. van der Heijden MGA, Klironomos JN, Ursic M, Moutoglis P, Streitwolf-Engel R, Boller T Wiemken A, Sanders IR Mycorrhizal fungal diversity determines plant biodiversity, ecosystem variability and productivity. Nature. 1998;396: 69-72.
12. Herridge DF, Peoples MB, Boddey RM. Global inputs of biological nitrogen fixation in agricultural systems. Plant Soil. 2008;311:1-18.
13. Strickland MS, Lauber C, Fierer N, Bradford MA. Testing the functional significance of microbial community composition. Ecol. 2009;90:441-51.
14. Oliver MA. Soil and human health: a review. Eur J Soil Sci. 1997;48:573-92.
15. Williams PN, Lombi E, Sun GX, Schekel K, Zhu YG, Feng X et al. Research Center for Eco-Environmental Sciences, Selenium characterisation in the global rice supply chain. Environ Sci Technol. 2009;43:6024-30.

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土壤科學在糧食體系與衛生安全的角色

土壤是生產糧食的天然資源，我們所消耗的絕大多數食物都是直接或間接來自於土壤。土壤的品質決定了糧食的量(卡路里)和質(營養品質和食品安全)。因此，保護土壤的物理性、化學性和生物性的完整對於保護全球的糧食安全是很重要的。土壤科學，提供了土壤品質和其永續的管理相關的新知。然而，土壤科學家並非獨自來保護全球的糧食生產系統，而是和環境工程師、農學家、營養學家、動物學家、社會學家一起合作，發展針對土壤保育、物資循環及環境保護的綜合性方法。

關鍵字：生物多樣性、污染、糧食安全、營養、土壤品質