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EDITORIAL

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# Sustainable soil management for food security

## 1 | INTRODUCTION

Food security is one of the major challenges of modern society (Prosekov & Ivanova, 2018). Globally food production needs to be increased by 70% in order to meet the demand of a growing population reaching 9.7 billion by 2050 (Cole et al., 2018). It was estimated that approximately 768 million people were in hunger as of 2021 (FAO, 2022b). The situation is exacerbated by the ongoing coronavirus pandemic, regional conflicts and global environmental changes, which pose a serious challenge to the United Nations sustainable development goal of ending hunger. Based on data from the United Nations Food and Agriculture Organization (FAO) (see Figure 1), the number of people in hunger has increased by 34% in the 5 years period between 2017 and 2021, which represents a reversal of trend in the previous two decades. The situation is more serious in Africa, where the number of people in hunger has been continuously rising since 2010 and has increased by 62% since then.

Soil is the ultimate defence of food security, producing nearly 95% of our food directly or indirectly (FAO, 2015). However, the health of global soil is threatened by a variety of pressing factors, including loss of soil nutrients (Lal, 2009), diminishing soil organic carbon (Smith, 2008), pollution (Beans, 2021), salinization (Singh, 2022), erosion (Borrelli et al., 2020; Starke et al., 2020) and decline in biodiversity (Guerra et al., 2021; Hou, 2022a). This has in turn resulted in both insufficient food production and food of poor nutritional quality, thus jeopardizing human health (Gashu et al., 2021; Oliver & Gregory, 2015). To address these challenges, we must enhance our understanding of balanced and integrated soil nutrient management, pros and cons of conservation agriculture, adaptation and mitigation of climate change and incorporation of innovative technologies such as big data and digital farming into practice.

## 2 | SOIL NUTRIENT MANAGEMENT AND CROP YIELD

Soil nutrient management and crop yield are one of the most important research topics in soil science (Havlin, 2020; Ray et al., 2012). Based on data from Web of Science, annual research output linking soil phosphorus and crop yield increased by nearly 12-fold since 1990, and in the same period, research linking soil nitrogen and crop yield increased by nearly 9-fold. As Figure 2 shows, the pace of increase accelerated since 2015, with the recent trends exceeding the long-term exponential growth trajectory. This is in coincidence with, but may also reflect a driver–effect relationship of, the United Nations Sustainable Development Goals established in 2015 (FAO, 2016; UN, 2015). The UN-SDG specifically calls for the elimination of hunger in SDG #2, and several other SDGs, such as SDG #1 for no poverty and SDG #3 for healthy lives, are all related to soil health and crop yield.

Sustainable crop yield requires a balanced nutrient supply. However, many smallholder farmers are not capable of achieving this due to the lack of awareness and know-how, as well as economic constraints (Chikowo et al., 2014; Njoroge et al., 2017). As nitrogen is the most often encountered nutrient limiting factor, many farmers have focused on nitrogen supply. In the north-western Himalayas of India, heavy reliance on urea application results in an average maize productivity of 2.5 t/ha, which is only 43% of the world average of 5.75 t/ha. This has been attributed to soil acidification, shortage of sulphur and potassium and general decline of soil health (Thakur et al., 2022). Excessive application of nitrogen can also result in water eutrophication due to leaching (Zou, Wang, et al., 2022). The management of soil nitrogen may be facilitated by natural plant species. A 23 years study in the United States showed that land with 16 perennial grassland plant species increased soil nitrogen by 30% ~ 90% in comparison with monocultures (Furey & Tilman, 2021).

Cropland phosphorus management represents a long-term sustainability challenge for many countries due to depleting phosphate rock reserves and low phosphorus use efficiency (Haygarth et al., 2014; Zou, Zhang, & Davidson, 2022). The supply of phosphorus, especially during the early plant height growth period, is a strong predictor of crop yield (Pedersen et al., 2022). The availability of phosphorus is affected by soil pH. Soil liming is a widely applied strategy in alleviating problems associated with soil acidification (Fageria & Baligar, 2008; Holland

  

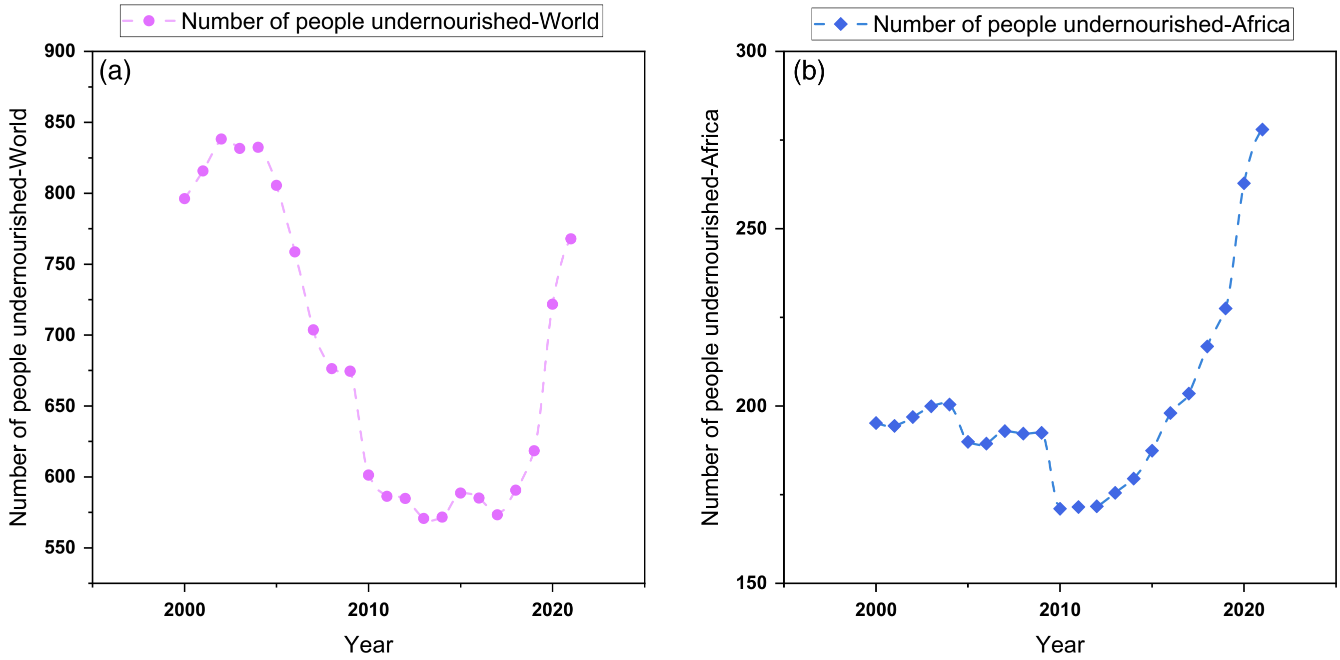


**FIGURE 1** Temporal trend of people in hunger: (a) number of people undernourished in the World; (b) number of people undernourished in Africa. Data source: https://www.fao.org/faostat/en/#data/FS

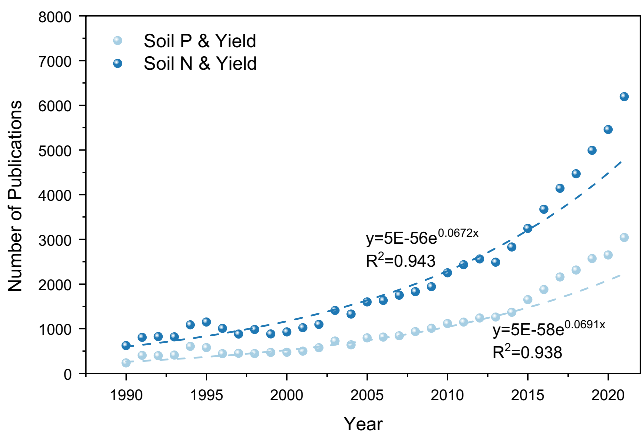


**FIGURE 2** Trend of research pertaining to soil nutrient and crop yield accelerated beyond exponential growth since 2015. The literature search was carried out in the Web of Science database on 10 December 2022

et al., 2018); however, it may affect phosphorus uptake due to its lower mobility under high pH. Therefore, it is important to coordinate liming and P-fertilization, in accordance with crop types and soil physicochemical properties (Christensen et al., 2022). Biochar application can effectively increase wheat yield in low-yield farmlands with low soil organic matter and insufficient nutrient contents (Dong et al., 2022). A 8-year-long field study in Ethiopia found that the application of both bone char and biochar can significantly increase maize and soybean, due to increased soil-P desorption capacity and enhanced P availability (Wakweya et al., 2022). Biochar application increased maize yield by 55% ~ 62% in saline-alkali soils in the Yellow River Delta of China (Wang et al., 2022).

## 3 | CONSERVATION AGRICULTURE PRACTICE

Conservation agriculture practices include minimum mechanical soil disturbance such as no-till, permanent soil organic cover with crop residues and/or cover crops, and species diversification with crop rotation (FAO, 2022a; Hobbs et al., 2008). When properly implemented, they can increase crop yield due to improved soil aggregation (Sithole et al., 2019; Veloso et al., 2020), higher water holding (Eze et al., 2020) and lower penetration resistance (Jat et al., 2018), while minimizing the impact to the environment and rendering carbon sequestration benefits (Chai et al., 2021; Islam et al., 2022). During recent years, the practice of conservation agriculture has expanded rapidly on a global scale. In 2015/16, approximately 12.5% of global cropland practiced conservation agriculture, mainly in South and North America (Kassam et al., 2019). However, the practice of conservation agriculture smallholder farmers in developing countries has rendered disappointing results (Giller et al., 2015). The adoption of conservation agriculture is also affected by farmland sizes and expected benefits (Lu et al., 2022).

The effect of conservation agriculture depends on planting choices, as well as site characteristics and weather conditions (Li et al., 2018; Sun et al., 2020). The species of cover crop affect root architecture and thus soil aggregate and penetration resistance (Grunwald et al., 2022). Chemical composition of cover crops, such as hemicellulose and lignin contents, affects the accumulation of labile and stable fractions of soil organic matter (de Carvalho et al., 2022). In Northeast China, a meta-analysis showed that no-till renders higher crop yield than conventional tillage practice when the mean annual temperature (MAT) is higher than 6°C; however, when MAT is lower than 3°C, no-till renders lower crop yield than conventional tillage (He et al., 2022). In such colder weather, rotational ridge tillage and subsoiling tillage may be the optimum tillage practice to maintain a high crop yield. An integrated cropping system combining relay planting, intercropping, strip rotation, soil mulching, and no-till was found to increase crop yield by 16%~50% while decreasing its environmental footprint by 17% in comparison with traditional monoculture cropping (Chai et al., 2021). By combining conservation agriculture with innovative technologies such as digital farming, the GHG emission associated with row crop agriculture can be reduced by 71% over the next 15 years (Northrup et al., 2021).

## 4 | CLIMATE CHANGE ADAPTATION AND CLIMATE MITIGATION

Climate change conditions such as rising temperature, severe drought and increased flooding all pose a threat to food security (Nottingham et al., 2020; Zurek et al., 2022), especially for the most under-developed countries such as in sub-Saharan Africa (Qin, 2022). Climate-smart soil management strategies can mitigate these risks (Hou, 2022b; Nyagumbo et al., 2022). Conservation agriculture practice discussed above can often align well with such climate adaptation strategies (Milder et al., 2011; Thierfelder et al., 2017). Under severe drought conditions, soil amendments such as biochar and straw ash was found to significantly increase soil water retention (Bruun et al., 2022). Rhizosphere microbiomes can also assist to render more drought-resilient crop production (de Vries et al., 2020).

Sustainable soil management can not only assist in climate change adaptation but also help to facilitate climate change mitigation. Soil represents the largest terrestrial carbon pool and holds much promise in regulating global climate (Gherardi & Sala, 2020; Hein et al., 2020; Walker et al., 2022). Depending on landscape position and soil texture, soil amendment such as biochar can be used to suppress GHG emission (Abagandura et al., 2022). The use of organic fertilizer can mitigate $N_2O$ emission in comparison with inorganic fertilizer (Chirinda et al., 2021; Lawrence et al., 2021). There are also trade-offs that we must address. For instance, future climate warming may increase crop yield in peatland, but it may also enhance GHG emission (Matysek et al., 2022). The water table depth may need to be managed delicately in order to reduce GHG emission while maintaining the productive use of peatlands (Evans et al., 2021). The complex dynamics and influencing factors make it difficult to make the real-time decision in soil management. A better understanding of quantitative relationships and modelling tools may help to solve practical problems. As an example, the decomposition of exogenous organic matters, such as animal manures and composts, can be simulated by quantitative models built upon extensive incubation experiments (see Figure 3) (Levavasseur et al., 2022). More of these types of predictive models need to be developed and validated to enhance our means of managing soil sustainably under climate change conditions.

## 5 | SOIL QUALITY INDICATORS, SPATIAL VARIATION AND DIGITAL MAPPING

Soil heterogeneity leads to spatial variation of crop yield, thus requiring site-specific soil nutrient management (Ameer et al., 2022). Best management practice relies upon the in-field measurement or remote sensing of soil quality indicators (Ren et al., 2022), as well as the digital mapping of their spatial variation (Gray et al., 2022; Keshavarzi et al., 2022). A systematic literature review on digital mapping of continuous soil attributes showed that the digital mapping literature is the most common in China and Australia, followed by the United States and Brazil (see Figure 4). Most publications render some sort of validation; however, most of them lack information on sampling design/support and lack uncertainty analysis (Piikki et al., 2021). Expert opinion may be combined with soil quality scoring functions to further optimize management practice (Ghorai et al., 2022; Mihoub et al., 2022).

## 6 | CONCLUSIONS

It is imperative to manage soil resources with sustainable means in order to ensure food security. Balanced

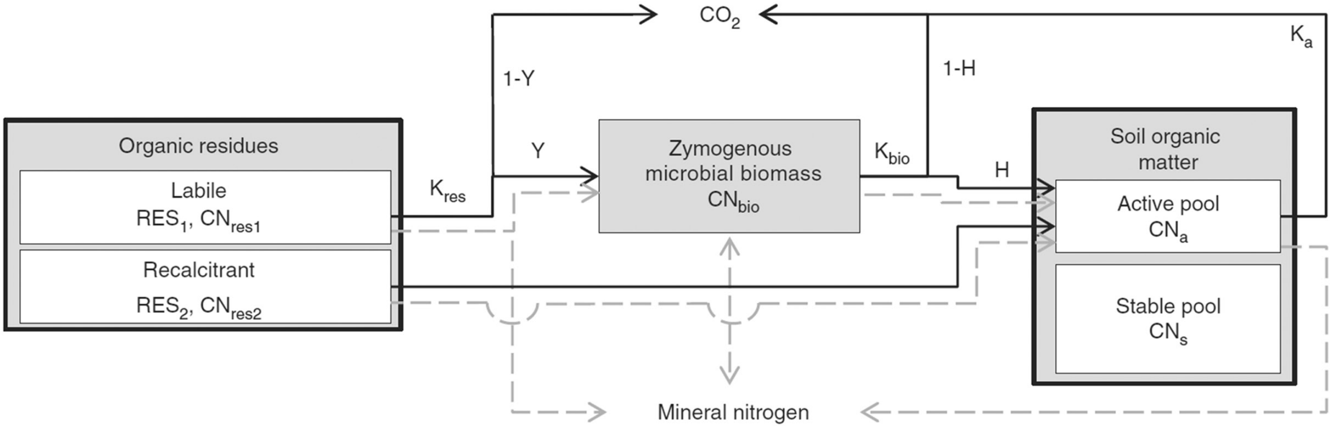


FIGURE 3 Decomposition model of exogenous organic matters (Levavasseur et al., 2022)

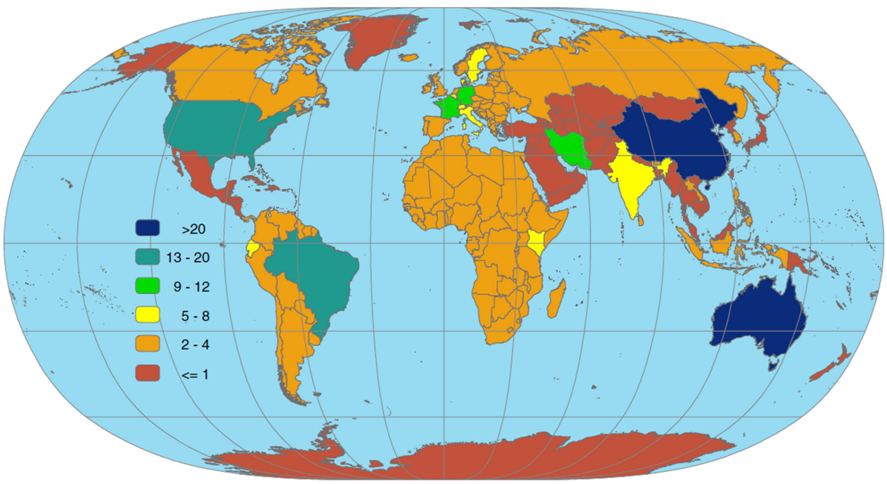


FIGURE 4 Distribution of existing studies on digital mapping of continuous soil attributes (Piikki et al., 2021)

supply and integrated management of soil nutrients such as nitrogen and phosphorus are a fundamental prerequisite for sustained crop yield. Conservation agriculture practices are instrumental in protecting the environment while increasing food production. Climate change such as severe drought and increased flooding pose a serious challenge to soil management, and farmers must adapt to these changing environmental conditions by adopting climate-smart soil management practice. Scientists have developed a range of tools, such as soil quality indicators and digital mapping methods, to empower soil management. However, there are still gaps between theory and practice. Researchers and policymakers need to work more toward the practicality of sustainable soil management.


## KEYWORDS

adaptation, conservation agriculture, food security, soil degradation, soil nutrient management



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