Advances in Agriculture and Biology (2019) 2(1): 48-54
REVIEW PAPER

Integrated use of organic and inorganic fertilizers improves soil health, growth and yield of wheat (*Triticum aestivum* L.)

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Received: 11 May 2019
Accepted: 19 August 2019

Abstract

Wheat (*Triticum aestivum* L.) is vital for global food security due to its nutrition and widespread consumption. To support the growing population, using both organic and inorganic fertilizers enhances soil health and wheat yield. Mineral fertilizers directly affect crop yield and soil quality. Soil organic matter (SOM) is a crucial component for soil quality, microbial activity, decomposition, and nutrient cycling. The interaction between fertilizer uses and soil health is a complex phenomenon. The choice of fertilizer type, amount and application method impacts soil microbial populations and properties. Long-term balance fertilizer application enhances soil microbial biomass, with multiple factors like nitrogen source and application method as well. Sustainable agriculture and environmental health require both organic and mineral fertilizers use for better production. Public education on fertilizer synergy, crop yields and soil health are essential to enhance the productivity of agricultural products. Excessive inorganic fertilizer use leads to adverse consequences, including heavy metal accumulation, pollution, and environmental degradation. Organic fertilizers offer a more sustainable soil fertility approach, improving soil properties and crop yields. Application methods, like band spreading, trailing hose and burial, reduce nutrient loss and enhance soil structure. Combining organic and inorganic fertilizers is more effective for crop growth and yield, addressing limited arable land and global food demand. Fertilizers have been vital in ensuring food security for the expanding world population. With the population projected to exceed 9 billion by 2050, integrated soil nutrient management is crucial. Fertilizer use also impacts soil erosion, leading to topsoil loss and soil health decline. Nutrient-rich topsoil is vulnerable to erosion, especially in regions with inadequate fertilizer use. Proper nutrient management is a key to mitigating soil erosion and protecting soil and the environment. Research into the relationship between fertilizer use, crop production and soil erosion is needed for sustainable agricultural practices.

Keywords: Environmental health, Inorganic fertilizers, Organic fertilizers, Soil health, Soil organic matter, Wheat

Citation: Abbas, Q., & Shafique, A. (2019). Integrated use of organic and inorganic fertilizers improves soil health, growth and yield of wheat (*Triticum aestivum* L.). *Advances in Agriculture and Biology, 2*(1), 48-54.

Introduction

Wheat (*Triticum aestivum* L.) is an essential cereal crop belonging to the Poaceae family and has emerged as a staple food in various regions across the globe due to its nutritional value and palatability (Slafer et al., 1994; Khan et al., 2016; Anser et al., 2018; Shafqat et al., 2019). Soil is considered as the core of life on earth. Fertilizers play a critical role in providing sufficient food for the current world population of over 7 billion individuals, and their significance is anticipated to grow further as we approach an estimated population of over 9 billion by 2050 (Alexandratos & Bruinsma, 2012). Mineral fertilizers are primarily known for their significant role in boosting crop yields. However, their impact extends beyond mere productivity enhancement. They also exert considerable influence over soil quality, health, and their overall capacity to better serve humanity (Yousaf et al., 2017). Various factors contribute to determining the quality and health of soil, with physical attributes like texture being a significant determinant. However, the core of soil quality resides in the fraction of soil organic matter (SOM). Despite its relatively small presence, SOM exerts a deep influence on overall soil health and its advantageous functionalities. Soil organic matter plays a crucial role in governing the diverse functions of microbial populations within the soil, including but not limited to the regulation of decomposition and nutrient cycling processes. The application of fertilizers can exert both positive and negative impacts on soil health. With appropriate tillage methods, regular nitrogen (N) fertilizer additions can strengthen SOM levels.

Organic matter significantly contributes to improving soil aggregate stability, effectively fortifying it against erosion and preventing soil degradation. However, the inherent changes brought about by nitrogen (N) fertilizers in the soil can lead to high acidity resulting in a subsequent decrease in soil pH, which adversely affects crop growth. The effect depends on how much nitrogen is used and the specific type of nitrogen applied. Calcareous soils commonly display resilience or buffering against these effects. Adverse effects on soil microbial populations resulting from fertilizer usage depend on the origin and method of N application, usually remaining localized and short-lived. However, continuous fertilizer use generally leads to an increase in soil microbial biomass. The degree to which mineral fertilizers promote both cost-effective crop production and enhance soil health depends on the application of ideal management practices. These practices encourage the combined utilization of organic manures along with mineral fertilizers whenever possible. Hence, there is a crucial need for broader public education regarding the symbiotic relationship between fertilizers, crop yields, and soil quality. Scientific research in soil and agronomy highlights that sustainable agricultural intensification and environmental health are mutually attainable objectives.

The consistent and prolonged application of synthetic fertilizers results in the frequent absorption and accumulation of heavy metals by plant tissues. This accumulation, in turn, reduces the nutritional value and overall quality of crops. Consequently, the excessive use of these synthetic fertilizers has led to pollution in soil, air, and water systems. This pollution occurs through nutrient leaching, degradation of soil structure, and the buildup of harmful chemicals in water sources (Tilman et al., 2002). This overuse contributes significantly to severe environmental issues and the loss of biodiversity. As a result, agrochemicals represent a significant contributing factor to pollution in developing countries and pose a significant risk to the health of both humans and livestock. While mineral fertilizers exhibit higher water use efficiency, total dry matter, grain, and straw yield compared to organic manures. Organic fertilizers (e.g. FYM, poultry manures, compost, humic acid etc) prove effective in enhancing soil properties. This improvement ultimately contributes to better crop responses.

Benefits of organic fertilizers to improve the soil health

The foremost challenge impacting crop production globally is poor soil fertility (Kopittke et al., 2019). This issue poses a significant threat to food security, especially due to the ever-increasing human population (Bruinsma, 2009). To meet the growing population's food demands, forests and marginal lands were converted into farmlands. However, this practice resulted in the extinction and endangerment of numerous plant and animal species. Using land reserves and marginal lands for farming is considered unwise. Thus, it becomes crucial to enhance soil fertility and the overall health of available land to boost food production and ensure global food security during existing and anticipated climate change challenges. Traditionally, mineral fertilizers were considered the primary solution for soil fertility issues due to their rapid nutrient release (International Food Policy Research Institute [IFPRI], 2002). However, the exclusive use of mineral fertilizers fails to enhance the soil's physical properties and soil fertility. Relying excessively on mineral fertilizers, without due attention to organic alternatives, can result in intensified soil erosion, surface and groundwater contamination, increased greenhouse gas emissions, and reduced biodiversity (Tilman et al., 2002). Moreover, mineral fertilizers are costly and pose challenges for many farmers (Tetteh et al., 2008). Consequently, there has been a shift in focus among various stakeholders towards the utilization of organic resources (Suge et al., 2011). The application of organic fertilizers offers a more sustainable approach to food production. Countless studies confirm that organic nutrient sources effectively maintain soil quality, enhance crop yields, and sustain productivity (Negassa et al., 2001; Vanlauwe et al., 2002; Suge et al., 2011).

Utilizing organic fertilizers: Maximizing their advantages through application techniques

The efficacy of organic materials as fertilizers greatly depends on their application methods. Applying organic fertilizers to the surface can lead to the loss of nitrogen (N) through ammonia volatilization and the loss of both N and phosphorus (P) through runoff and erosion. To minimize wastage and nutrient losses, several judicious application methods can be employed such as band spreading, trailing hose application, burying, rapid soil incorporation, and the use of nitrogen inhibitors (Misselbrook, 2019). Band spreading involves applying organic material in narrow bands typically a few centimeters away from crops. This minimizes the material's exposure to the atmosphere, reducing ammonia volatilization. To further decrease denitrification, band spreading should occur during cooler weather with optimal soil moisture and appropriate application rates. The crop canopies act as a barrier, further reducing ammonia volatilization. Burying organic amendments at a depth of 5-30 cm depending on crop establishment is another effective method. Deeper burying can be done before crops are planted, while shallower burial is suitable for already established fields. This technique significantly reduces N loss through ammonia volatilization and erosion. Manure can be rapidly incorporated into the soil during tillage (before planting) or using hand implements, reducing N and P losses through volatilization and runoff.

In conditions conducive to high denitrification, nitrification inhibitors can be added to organic fertilizers to slow down the conversion of ammonium to nitrates, a precursor to the denitrification process. It is crucial to apply organic fertilizers during cooler times of the day and at the correct rates to minimize nutrient losses. Numerous studies have shown increased crop yields with organic fertilizer application compared to the use of equivalent nutrients from mineral fertilizers (Palm et al., 1997; Vanlauwe et al., 2001; Giller, 2002). According to Zia et al. (2000), the continuous use of chemical fertilizers, even in balanced proportions, cannot sustain crop productivity due to soil health deterioration. While the application of organic manures or wastes alone has proven beneficial (Ibrahim et al., 1992; Alam & Shah, 2003), integrated use of organic wastes and chemical fertilizers has shown even more promising results (Mian et al., 1989; Nasir & Qureshi, 1999; Khanam et al., 2001; Alam et al., 2005).

The wheat crop demonstrates remarkable adaptability to diverse agro-climatic conditions and thrives in numerous countries worldwide. Recognized for its high protein content, wheat holds significant agricultural importance. Globally, wheat is grown on about ten million hectares and provides about one-fifth of the world's total calorie intake, producing a substantial 621 million tons of grain for the global population (Reynolds et al., 2006). This crop fulfills around 73% of the average diet's protein and caloric needs (Hossain et al., 2003). Pakistan faces critical challenges related to food security and a growing energy crisis due to its insufficient food production and a rapidly increasing population which is currently growing at a rate of 2.6 percent annually (Qazilbash, 2002). Although mineral fertilizers offer a rapid and effective solution, their use incurs substantial energy costs and raises environmental concerns. Expanding food production via available resources presents limited options. Crop yields are inhibited by water scarcity particularly affecting cereals (Anonymous, 2014). Recognizing the significance of both organic manures and inorganic fertilizers, a study was formulated to examine the potential enhancement of water use efficiency, growth, yield attributes of wheat, and soil properties through their application (Mandal et al., 2005).

Water scarcity poses a significant challenge to arid agriculture in Pakistan. To optimize crop yield, farmers employ moisture conservation techniques. The elevated summer temperatures in Pakistan's arid zones intensify moisture loss, primarily due to the low organic matter content, which rapidly depletes through decomposition. Incorporating organic amendments into the soil can effectively increase its organic matter content, thereby enhancing moisture retention and making nutrients more available to plants. As soil temperature and organic matter content exhibit an inverse relationship, a higher organic matter content could potentially reduce the rate of moisture depletion. Several studies indicate that combining organic manures with inorganic fertilizers results in higher yields compared to using only chemical fertilizers (Sarwar et al., 2008).

The soils in Pakistan exhibit low organic matter contents typically less than 5%. Implementing organic matter and compost applications can help in replenishing these calcareous soils. This is especially crucial in an area characterized by a hot arid climate, where the judicious use of organic amendments and water can significantly reduce input costs and enhance crop yields. At the Arid Zone Research Centre (AZRC), a field experiment was carried out on wheat (Subhan et al., 2017). The utilization of inorganic fertilizer notably increased the total dry matter, grain, and straw yield. The NPK treatment demonstrated higher water use efficiency primarily due to the greater grain yield. Moreover, treatments involving cattle manure and compost significantly improved bulk density, porosity, and organic matter content. However, the moisture content and water holding capacity did not show significant changes as a result of these treatments. The study suggests that water use efficiency, particularly in terms of grain yield, was higher in plots treated with mineral fertilizer. Nonetheless, compost and manure treatments were comparable and exhibited significant improvements in soil properties. Research has shown that augmenting organic matter concentrations in soil can notably boost cereal yields (Sarwar, 2005) and improve various soil properties such as density, aeration, and water retention for enhanced plant growth and root development. Compost, being rich in organic matter, serves as a vital source of nutrients for plants' growth. Its incorporation not only increases soil organic matter but also positively impacts the physical and chemical attributes of the soil, ultimately leading to increased crop yields. A substantial portion of wheat cultivation in Pakistan occurs under rainfed conditions, contributing around 10-12% of the total wheat production in the country (Rashid et al., 2003). Specifically, in NWFP, 57 to 60% of the wheat-growing area depends on rainfed land, yielding an average of 900-1200 kg ha-1 (MINFAL, 2005). The historical practice of applying farmyard manure (FYM) has proven beneficial over centuries, enhancing crop yield, soil fertility, organic matter content, microbiological activity, and structural integrity for sustainable agriculture in subsequent years (Blair et al., 2006; Kundu et al., 2007). However, the combined use of both organic and inorganic fertilizers has demonstrated superior effects on wheat growth, development, and yield components compared to their individual application (Badaruddin et al., 1999; Hossain et al., 2002; Manna et al., 2005).

The limited availability of additional land for crop production, coupled with decreasing yields of major food crops, raises concerns about agriculture's capacity to sustain a growing population that is expected to exceed 7.5 billion by 2020. Future strategies aimed at boosting agricultural productivity must prioritize the efficient and sustainable use of available nutrient resources. Integrated nutrient management plays a pivotal role in fostering proper plant growth, optimizing water usage, and ensuring sound soil and land management. These measures are crucial for the long-term sustainability of agricultural productivity. An overarching strategy to elevate crop yields and maintain them at high levels necessitates an integrated approach to soil nutrient management. Acknowledging that soil serves as the primary reservoir of essential plant nutrients crucial for plant growth, their proper management significantly influences soil fertility and agricultural sustainability. Besides traditional farm manures, the substantial amount of waste produced in cities, towns, and villages throughout Pakistan not only pollutes their atmosphere but also holds potential for enhancing soil fertility and crop productivity. Considering these circumstances, this study was conducted to investigate the impact of mineral N (urea) and organic manures (such as farmyard manure, poultry manure, and municipal waste), either individually or in various combinations, on the yield and yield components of wheat.

The primary catalyst driving human interventions during the past century has been the multiplying of the world population. This exponential increase necessitated a fundamental shift in soil and crop management to meet the amplified demand for food (Lal & Stewart, 2010). The sustenance and clothing of the burgeoning global population required expanded cultivation on additional lands and heightened productivity from existing agricultural lands. A significant contributor to ensuring global food security has been the widespread utilization of commercial mineral fertilizers. Examining global trends and projections in fertilizer use becomes essential in this context. In 2012, the world used 178.9 million metric tonnes (Mt) of nutrients in fertilizers. Among these, nitrogen (N), phosphorus (P) as P_2O_5, and potassium (K) as K_2O accounted for 109.1, 41.1, and 28.7 Mt, respectively. A little over half of this total (50.8%) has been applied to cereal crops (Heffer, 2013). The availability and application of nitrogen-based fertilizers have been pivotal in determining yields across major crops (Glenn et al., 2014). Simultaneously, estimates provided by the World Resources Institute indicate a substantial 69% disparity between the quantity of crop calories produced in 2006 and the anticipated demand by 2050. This disparity highlights the potential gap between current agricultural outputs and the future nutritional needs of an expanding global population. The Food and Agriculture Organization's revised projection anticipates a 60% rise in global agricultural production by 2050 compared to 2005-2007 (Alexandratos & Bruinsma, 2012). Closing this gap solely through increased agricultural production would demand an even more significant surge in total crop production from 2006 to 2050 compared to the growth experienced from 1962 to 2006, representing an additional 11% increase (Searchinger et al., 2013). The need for better food production brings about the requirement for more intensified agricultural methods owing to the limited availability of arable land. It is estimated that over 48% of the current global population more than 7 billion people rely on increased crop production facilitated by the application of nitrogen-based fertilizers, created through the chemical engineering innovation known as the Haber-Bosch process, a groundbreaking development from the early 1900s represent a pivotal advancement in human history (Erisman et al., 2008). Meeting the rising global food demands and preventing extensive famine becomes unfeasible without the contributions of fertilizers. Multiple extensive studies carried out in the USA, England, and tropical regions indicate that a minimum of 50% of crop yields is directly attributable to nutrient inputs from commercial fertilizers (Stewart et al., 2005). The future is likely to see an even greater dependency on fertilizer use for global food production. The utilization of fertilizers significantly boosts global staple food production, potentially doubling the yield. This increased yield can help limit the necessity to convert additional forested lands into agricultural areas (Roberts, 2009).

Fertilizer use reduces soil erosion

Significant literature has explored the human impact on soil erosion (Lal, 2007). However, the comprehensive documentation concerning the correlation between different soil erosion processes (such as erosivity and erodibility) and agricultural practices, particularly the utilization of mineral fertilizers remains relatively limited. In many tropical and subtropical areas, the inadequate provision of nutrients, either through fertilizers or organic manures, along with poor nutrient management rapidly reduces soil productivity. This leads to the rapid erosion of nutrient-rich topsoil. The scarcity of essential nutrients in agricultural lands primarily caused by insufficient fertilizer application is common in various regions of Sub-Saharan Africa. It leads to a decline in soil fertility, potentially intensifying soil erosion due to inadequate plant cover. Local nutrient sources such as biological nitrogen fixation and manure recycling are not consistently and optimally utilized. The imbalance between crop harvests and necessary nutrient inputs leads to nutrient depletion, decreased soil organic matter, deteriorating soil health, and an increased susceptibility to land degradation caused by erosion. Soil erosion becomes problematic when there is insufficient ground cover to shield the soil from the effects of rainfall and wind. This combined with the decrease in soil organic matter that reduces aggregate stability leads to high runoff and erosion. As a result, it may cause elevated sedimentation and silt in reservoirs and coastal areas, potentially triggering eutrophication in rivers and lakes.

Conclusion and future perspectives

The concept of soil health is continually evolving, and it's evident that forthcoming research on fertilizer use in crop production and cropping systems must encompass soil considerations alongside the primary focus on crop yields. Securing funding for soil health research may prove challenging unless it is linked to enhancing cropping outcomes, such as yield improvements or more efficient input utilization. The impact of fertilizers on soil health has conventionally centered on nitrogen (N), largely overlooking the potential influence of phosphorus (P). Potassium, secondary nutrients, and micronutrients have been largely unexplored in their influence on soil health, assumed to have minimal impact compared to major nutrients. To gain a comprehensive understanding of soil health, it is crucial to thoroughly document the stability of soil organic matter (SOM) and the long-term impacts of organic residues across different cropping systems. Long-term agricultural experiments carried out in various agro-ecological zones globally can offer valuable datasets relevant to soil quality. Studies on soil health cover a wide range of climatic regions worldwide, but there is limited exploration into the detailed effects of rainfall, soil moisture, and temperature on soil health that warrants further investigation. Modeling presents itself as a valuable tool to bridge this gap.

Given the limited and occasionally contradictory reports regarding the impact of fertilizers on soil health, coupled with substantial gaps in understanding various soil organisms, it is imperative to reconcile conflicting data and delve into the enigmatic world of soil microbes. Diverse microbial groups respond disparately to repeated mineral fertilizer applications, influenced by a myriad of environmental and crop management factors. Extensive studies are warranted to untangle the intricate interactions among environmental elements, types and rates of fertilizers, and specific soil microorganisms. While many studies have evaluated the effects of crop residues and organic materials on soil health, a wide spectrum of residues, from rapidly decomposing legumes to more resistant lignified cereal straw, should be considered. In efforts to reduce cultivation costs and enhance soil health, conservation agriculture systems are gaining popularity globally. These systems minimize soil tillage and retain crop residues to bolster SOM. Therefore, it is imperative to establish suitable fertilizer management strategies within these systems to maintain or improve soil health.

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