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Assessment of organic & biofertilizer with sulphur on growth and yield of Maize by residual effect in maize - wheat cropping system: A review

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Abstract

Organic and biofertilizers, combined with sulphur, on the growth and yield of maize, focusing on their residual effects within a maize-wheat cropping system. Maize and wheat are critical crops in rotation systems aimed at optimizing soil fertility and agricultural productivity. Organic fertilizers, including compost and manure, and biofertilizers, such as nitrogen-fixing bacteria and phosphorus-solubilizing fungi, are recognized for enhancing soil health and crop performance. Sulfur, a vital nutrient for plant growth, complements these inputs by correcting deficiencies and improving nutrient uptake. The review highlights that organic and biofertilizers generally promote better maize growth parameters - such as increased germination, plant height, and root development and improve yield by enhancing soil fertility and microbial activity. Sulphur's role is crucial in correcting deficiencies and supporting maize productivity. Residual effects from these inputs positively impact subsequent crops, including wheat, by maintaining or improving soil nutrient status and overall health. Integrating organic and biofertilizers with sulphur not only boosts maize yield but also contributes to sustainable farming practices by reducing reliance on synthetic fertilizers and promoting long-term soil fertility. The findings underscore the importance of balanced nutrient management and ongoing soil monitoring to maximize the benefits of these inputs. Future research should focus on optimizing fertilizer combinations and rates to enhance residual effects and ensure economic and environmental sustainability in maize-wheat cropping systems.

Keywords: FYM, vermicompost, maize, wheat, biofertilizers, sulphur, growth, yield

Introduction

The cultivation of maize (*Zea mays*) and wheat (*Triticum aestivum*) as a combined cropping system has emerged as one of the most economically beneficial agricultural strategies in the Indo-Gangetic Plains of India. Among various cropping patterns centered on maize, the maize-wheat sequence is particularly significant, ranking third after rice-wheat and rice-rice sequences (Jat *et al.*, 2020) ^[10]. Covering an area of 1.8 million hectares this system contributes about 3% of India's total food grain production and is crucial for food security, nutritional sustenance, and environmental stability.

In this context, Bihar is a key player, with a notable contribution of 0.72 million hectares to the total cropped area. Food grains dominate the net cropped area, accounting for around 78%. Bihar's contribution to the national gross cropped area is 14%, and it consumes 21% of the total NPK (Nitrogen, Phosphorus, and Potassium) fertilizers. Maize, also known as corn (*Zea mays*), is a crucial component of global agriculture, serving as a staple food for humans, animal feed, and a valuable raw material for various industries.

Globally, maize is a major crop, with approximately 58% used for animal feed, 16% for human consumption, and 26% for bioethanol production. It is the third most cultivated food crop, following rice and wheat in both area and production. The United States leads the world in maize production, contributing nearly 35% of the global output. The U.S. achieves a remarkable productivity rate of over 9.6 tons per hectare, which is about twice the global average of 4.92 tons per hectare. In comparison, India's maize productivity is lower at 3.02 tons per hectare. India grows maize on 9.47 million hectares, producing 28.72 million tonnes with an average productivity of 3032 kg per hectare. Key maize-producing states in India include Andhra

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Pradesh, Karnataka, Rajasthan, Maharashtra, Bihar, Uttar Pradesh, Madhya Pradesh, and Himachal Pradesh, which together account for more than 80% of the total production. Specifically, in Uttar Pradesh, maize covers 7.87% of the land and contributes 5.14% to the total production, with an average productivity of 1981 kg per hectare (Anonymous 2023) ^[3]. Maize, often referred to as the "queen of cereals," is valued for its adaptability across various agro-ecosystems and its high genetic yield potential. It thrives in tropical, subtropical, and temperate regions and makes efficient use of solar radiation. The grain composition includes 72% starch, 10% protein, 4.8% oil, 5.8% fiber, 3.0% sugar, and 1.7% ash, making it a leading crop for high carbohydrate accumulation per unit area per day.

Wheat, another crucial crop, is essential for global food security, providing about 20% of the world's food needs and contributing over 19% of the calories and 11% of the proteins required for human nutrition. India ranks second in global wheat production, with wheat cultivated on 29.58 million hectares and yielding 99.70 million tonnes, giving an average productivity of 3371 kg per hectare. In Bihar, wheat covers approximately 9.75 million hectares, producing 21.88 million tonnes with an average yield of 3069 kg per hectare (Anonymous 2023) ^[3].

Both maize and wheat require substantial nutrients and respond well to increased levels of inorganic fertilizers, reaching their full yield potential when provided with balanced nutrients at the right times. The use of chemical fertilizers is essential to counteract soil nutrient depletion. These fertilizers play a crucial role in boosting yield and maintaining nutrient balance by replenishing soil nutrients, thereby enhancing soil fertility and productivity. Recent data indicates that nearly 50% of the increase in food grain production can be attributed to fertilizer use. For example, producing 1 ton of cereal grains requires approximately 20 kg of nitrogen and 4 kg of phosphorus per hectare. Without fertilizers, India would need two to three times more land to meet its food grain demands (Cuzzolino *et al.*, 2021) ^[9].

However, the long-term health of the soil and sustained crop productivity cannot rely solely on fertilizers, as they lack secondary and micronutrients. The continuous and disproportionate application of high-analysis inorganic fertilizers, combined with insufficient addition of organic matter in intensive cropping systems, has led to a significant decline in soil organic matter. This has caused multiple nutrient deficiencies, especially in secondary and micronutrients. Additionally, soil degradation, including erosion, compaction, salinization, and acidification, has further exacerbated the problem, resulting in reduced soil fertility and lower crop yields (You *et al.*, 2021) ^[16]. These challenges present significant obstacles to achieving the agricultural intensification needed to provide quality food for the rapidly growing population.

Sulphur has become the fourth major limiting nutrient in crop production, alongside the well-known nitrogen, phosphorus, and potassium (NPK) trio. Intensive farming practices, high-yielding crop varieties, and the use of sulphur-free fertilizers have led to sulphur deficiencies in soils, especially in intensive cropping systems. This highlights the importance of prioritizing sulphur as a critical plant nutrient. Compared to the significant use of NPK nutrients, sulphur supplementation through fertilizers remains quite limited. For instance, in Uttar Pradesh, sulphur addition through fertilizers is as low as 2.38 kg per hectare, which is only 2.32% of the total NPKS consumption. This insufficient sulphur input results in a negative balance, with the amount of sulphur removed by crops far exceeding its replenishment. This imbalance has led to the depletion of soil

sulphur reserves, impacting soil fertility.

Sulphur plays a crucial role in primary metabolism in plants and in the synthesis of secondary metabolic products in certain plant groups. It is essential for managing crops by aiding in resistance to environmental stress and combating pests and diseases. Moreover, sulphur contributes not only to increased yield but also to improved crop quality through its impact on protein metabolism and oil synthesis. A study by You *et al.* (2021) ^[16] demonstrated that applying sulphur at a rate of 30 kg per hectare led to significant increases in cystine, methionine, and protein content by 5.0%, 8.0%, and 1.0%, respectively.

In addition to chemical fertilizers, organic manures provide an excellent source of nutrients, including nitrogen, phosphorus, potassium, and secondary and trace elements. They enhance soil organic matter content, promoting a desirable soil structure and porosity vital for root growth, gas exchange, and water retention. These organic sources release nutrients gradually due to their slow decomposition, ensuring sustained nutrient availability and long-lasting effects in the soil. This contributes to improved soil physical, chemical, and biological properties, ultimately bolstering soil health and crop productivity.

Various organic manures, such as well-rotted farmyard manure (FYM), vermicompost, and green manures, are used to achieve these benefits. Vermicompost, produced through the digestive processes of different earthworm species, is rich in nutrients and introduces beneficial microbes and active metabolites like gibberellic acid, cytokinin, auxin, and vitamins. The application of well-decomposed FYM has stood the test of time, playing a crucial role in enhancing crop yields, increasing soil organic matter, and fostering microbial activity, which in turn improves soil fertility and aggregation. Balancing the application of N, P, K fertilizers with FYM has proven to be a successful strategy for boosting crop yields in maize-wheat cropping systems (Berg *et al.*, 2021) ^[7].

In the field of sustainable soil management, biofertilizers have gained significant attention for their role in maintaining long-term soil fertility and sustainability. They achieve this by fixing atmospheric di-nitrogen and mobilizing macro and micronutrients into forms that are easily accessible to plants. Various microorganisms, such as *Bacillus*, *Pseudomonas*, and fungal genera like *Penicillium* and *Aspergillus*, contribute to this process. These environmentally friendly and cost-effective agricultural inputs supplement mineral nutrition and support plant growth. Common biofertilizers include nitrogen-fixing soil bacteria (*Azotobacter*, *Rhizobium*), nitrogen-fixing cyanobacteria (*Anabaena*), phosphate-solubilizing bacteria (*Bacillus*, *Pseudomonas* spp.), and arbuscular mycorrhizal (AM) fungi.

Azotobacter, a free-living nitrogen-fixing aerobic diazotroph, is used in various non-leguminous crops, particularly paddy, cotton, and vegetables. Its growth is influenced by the soil's organic matter content. Similarly, phosphate-solubilizing bacteria are non-specific microbes that enhance phosphorus availability by converting insoluble forms into soluble forms, effectively promoting phosphorus uptake by plants. These biofertilizers play an integral role in Integrated Nutrient Management (INM), significantly contributing to soil sustainability and long-term crop productivity.

Although research since 1948 on the use of phosphate-solubilizing microorganisms (PSMs) as plant inoculants has shown that native PSM populations in soil contribute significantly to phosphorus cycling in ecosystems, PSM inoculants do not mobilize sufficient phosphorus to alter the nutritional environment of crops under field conditions

(Raymond *et al.*, 2021) ^[14]. Nevertheless, the use of these microorganisms offers an environmentally friendly and low-impact approach to enhancing plant nutrition. This study aims to evaluate the impact of various treatments on the growth and yield attributes of maize and wheat, while also assessing their direct and residual effects.

A positive and significant response of *Azotobacter* was observed with lower doses of inorganic fertilizers compared to higher doses. The term "bio-effector" was introduced to encompass the full range of plant growth-promoting properties exhibited by microorganisms (PGPMs) and natural active substances (non-microbial biostimulants). The categorization of plant growth-promoting properties into bio-control agents acting against pests and pathogens and biostimulants with other beneficial functions was intentionally avoided.

An analysis by Herrmann *et al.* (2022) ^[11] found no significant differences between bio-effector categories. The overlapping beneficial effects reported for many microbial and non-microbial bio-effectors, such as root growth promotion, scavenging of reactive oxygen species (ROS), and effects on hormonal balances (Sani and Yong, 2022) ^[13], might partially explain the observed similarities. Additionally, the practice of testing only the most promising bio-effector-crop combinations in the field, based on results from greenhouse experiments, represents a potential experimental bias. This could explain why the response ratio in this study differed less markedly compared to other studies.

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