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REVIEW ARTICLE

An overview of foliar application of macro and micronutrients on the yield of maize in Ghana

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ABSTRACT

Maize is a major staple crop in Ghana which plays a significant role in consumer diets. For some time now, the farming methods used by the farmers have been negatively affected by components such as climate, soil nutrient depletion, and constant monocropping resulting in the adoption of inorganic fertilizers. Conventional fertilizers supplied through soils are subjected to slow release of nutrients, leaching, fixation, surface runoff, erosion, and volatilization, which hinders optimal plant growth and yield. Foliar application of fertilizer offers an alternative method of fertilizer application that supplies nutrients directly to the stomata and cuticle of the leaves of maize thereby enabling rapid absorption and enhancing crop vigor. The The main objective of this paper is to review research papers which explores the potential of foliar application of vital nutrients – phosphorus (P), sulphur (S), zinc (Zn), and iron (Fe) – to improve the yield of maize crop. According to the literature gathered, foliar fertilization in combination with soil applied fertilizers emerges as a promising strategy, particularly in addressing nutrient deficiencies and stress scenarios. The efficient uptake of nutrients through leaves, as opposed to traditional soil-based approaches, holds promise for augmenting yield and enhancing protein content in maize crops. Notably, prior research highlights the efficacy of foliar-applied P, S, Zn, and Fe in significantly boosting grain yield. By understanding the complex mechanisms of nutrient absorption and the advantages of foliar application, the agricultural sector can explore innovative avenues to surmount soil-related challenges and achieve sustainable crop development.

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INTRODUCTION

Maize (corn) stands as one of the most widely cultivated cereal crops in Ghana and plays a significant role in the diets of consumers. For instance, it was discovered in a survey conducted nationwide in the year 1990 that 94 percent of households in Ghana depend on maize for their day-to-day meals (Morris *et al*., 2001). The annual yield of maize in Ghana is 2.26 tons per hectare which is far lower than the potential yield of 5.50 tons per hectare (MoFA, 2018), this is mostly because of low soil fertility, which is frequently improved by the use of mineral fertilizers. According to research by Beneh *et al*. (1990), maize-growing fields in Ghana have relatively low amounts of organic carbon (1.5%), nitrogen (0.2%), and potassium (<100mg/kg). Due to the low organic carbon levels in the soil, the average yield of maize is low despite the extensive use of mineral fertilizers, and this is as the result of poor nutrient holding capacity and low microbial activity. In such circumstances, application of foliar fertilizers is proven to be the efficient and cost-effective method in making essential nutrients available to plants, compared to application of fertilizers in soil (Lovatt, 2013). The application of smaller but more potent amounts of fertilizers through the leaves is essential for a healthy crop. Despite the usual practice of applying nutrients to the soil, foliar fertilization during critical crop developmental phases is important to obtain the yield potential of maize in Ghana (Lovatt, 2013). Foliar fertilizer enhances fertilizer management techniques by decreasing nutrient accumulation in soil and aquatic systems, minimizing eutrophication, salinity, NO_3 pollution, and so avoiding health problems (Lovatt, 2013). Over a period of time, the methods employed by farmers have been adversely impacted by factors such as climate variations (Ismaila *et al.*, 2010), diminishing soil fertility, insufficient application of external inputs (Fosu *et al.*, 2004; Fening *et al.*, 2011), and persistent monoculture practices (Wopereis *et al.*, 2006). To address the depletion of soil nutrients effectively, the application of mineral fertilizers is often involved (Bationo *et al.*, 2007). Therefore, ensuring optimal quantities of mineral nutrients, coupled with a well-balanced supply of macro- and micronutrients, represents a viable approach for enhancing crop yields (Zubillaga *et al.*, 2002).

Micronutrients are required in small quantities to directly or indirectly enhance processes such as photosynthesis, respiration, protein synthesis, and reproduction (Marschner *et al.*, 1995). It was found that the application of foliar fertilizers as a supplementary fertilizer enhanced the biomass of maize (Jakab *et al.*, 2016) (Balawejder *et al.*, 2016) as it provided rapid absorption and utilization of nutrients directly in the metabolism of plant (Bindraban *et al.*, 2015). In Ghana's maize production, foliar fertilization is a novel and under-utilized technique. There are no suggested application rates or schedules of foliar fertilizers for integrated nutrient management (INM). Therefore, comprehending the effect of foliar application of micro and macro nutrients on maize yield is essential. The review seeks to shed light on the less addressed topic to boost corn yield at the lowest possible cost using foliar fertilization.

Maize as a means of subsistence in Ghana

Maize is a staple crop in Ghana, providing a substantial source of calories to its consumers. This has led to its predominance in the Northern region of the country, effectively replacing pearl millet and sorghum (SRID-MoFA, 2011). A nationwide survey highlights that maize contributes more than half of Ghana's total cereal production, with an estimated annual growth rate of around 1.1% (IFPRI, 2014). Notably, maize and its derivative products constitute a significant portion of household food expenses, accounting for 10.8% and 10.3% of expenditure for both the poor and middle-income groups, respectively (Morris *et al.*, 2001). Despite this, the overall maize production in Ghana, in terms of cultivation area, has remained steady due to traditional farming practices (MiDA, 2010). The crop's significance extends to its substantial contribution to consumer diets. In Sub -Saharan Africa, approximately 50% of the population relies on various maize varieties for sustenance (Morris *et al.*, 2001). This leads to a diverse consumption of maize, from porridges and pastes to grits and even beer. Maize, especially in its green (fresh on cob) form, plays a crucial role in bridging nutritional gaps. The crop effectively helps alleviate the widespread hunger gap during dry seasons in various parts of Africa (Okoruna, 1995). However, its role in combating malnutrition, particularly in infants and children, is limited due to its relatively low protein and vitamin A content (Abbiw, 1990).

Origin and Maize Production in Ghana

Maize, scientifically known as *Zea mays* L., belongs to the Poaceae family. It originated from Central Mexico (Matsuoka *et al.*, 2002) about 9000 to 6000 years ago Benz, (2001) and was later introduced into Africa in the 16th century. Christopher Columbus introduced maize to Europe in the year 1492 from Central and Southern America. Its cultivation later spread into all parts of Africa by the Dutch in Southern Africa (Ogundele *et al.*, 2004). The world's demand for food and water is increasing at a high rate hence there is the need for production of staple food crops to be increased at a rapid rate. It is estimated that food production must be intensified by 70% to feed an expected growing population of 9.6 billion by 2050 (Foley *et al.*, 2011). Therefore, producers should be able to face challenges like soil nutrient losses, environmental challenges and unstable weather conditions which are the causes of major yield loss threatening food security in the world (FAO, 2009). In Ghana, maize is grown in the tropical rainforest, semi-deciduous forest and guinea savannah regions because of the adequate supply of moisture which is a delicate factor for grain yield of maize. A significant proportion of maize production in Ghana, approximately 60%, takes place in the Northern, Ashanti, Brong-Ahafo, Western, and Eastern regions (SRID and MOFA, 2007). The country's annual maize production stands at 1,100,000 metric tonnes, covering an area of 755,300 hectares (SRID and MOFA, 2007). Despite possessing a yield potential of 7.5 metric tonnes per hectare, the actual yield is currently only 1.73 metric ton/hectare. This emphasizes Ghana's underutilization of its agricultural capacity. Low yield is largely attributed to inadequate fertilizer application, necessary to replenish soil nutrients (SRID and MOFA, 2007).

Soil and climatic requirements of maize

Optimal growth conditions for maize comprises a well-drained sandy loam soil, having a pH range between 5.7 and 7.5, along with evenly distributed rainfall averaging 500-800mm (FAO, 2005). Maize thrives on soils abundant in nitrogen, phosphorus, and potassium. Yet, the major maize-growing agro-ecological zones in Ghana have soils deficient in organic carbon (<1.5%), exchangeable potassium (<100 mg/kg), total nitrogen (<0.2%), and available phosphorus (<10 mg/kg) (Benneh *et al.*, 1990; Adu, 1995). These soils are often shallow and interspersed with iron and manganese concretions (Adu, 1969). Despite these challenges, soil fertility management remains poor due to inadequate external input application, leading to low maize productivity (Adu, 1995). The cultivation of maize thrives in tropical, sub-tropical, and temperate climates (FAOAGL, 2002), requiring temperatures between 18 and 32°C (Awuku *et al*., 1991). Soil water availability significantly influences rain-fed maize production, with moisture scarcity during tasseling and grain filling stages adversely affecting yield (Roygard *et al*., 2002). Moisture stress results in reduced assimilate flux to the ear's development, compromising grain formation and growth (Westgate and Bassetti, 1990; Schussler and Westgate, 1995). Moisture stress leads to a 17% annual yield loss in tropical regions (Edmeades *et al*., 1992), and accounts for 60% of individual losses across South Africa's seasons (Rosen and Scott, 1992). High temperatures during grain filling have shown notable yield loss, exemplified by a 42% reduction in grain weight per plant due to a temperature rise from 25/15 to 35/15°C (Badu-Apraku *et al*., 2012). Maize yield is negatively affected by temperatures exceeding 32°C, while optimal yields are attained below 30°C (Adjetey, 1994).

Nutrient uptake mechanisms in maize

Maize plants acquire nutrients from the soil through their roots, and subsequently, these nutrients are transported within the stems and leaves. In cases where soil water availability decreases, the movement of nutrients is hindered, resulting in unfavorable repercussions for plant growth and development (Neina, 2019).

Nitrogen, phosphorus and potassium nutritional role in maize and their deficiency symptoms

Nitrogen holds crucial significance for photosynthesis, enhancing leaf pigmentation, and contributing substantially to grain yield. Maize plants require nitrogen immediately after germination to stimulate the growth of stems, leaves, and ear structures. The demand for substantial nitrogen increases during the tasseling and silking stages. Among the essential macronutrients, nitrogen is particularly vital for promoting effective vegetative and reproductive development in maize. Inadequate nitrogen supply leads to substantial growth reduction, given its role in protein and nucleic acid formation within maize plants (Adediran and Banjoko, 2003). Nitrogen also serves as a vital component in various compounds, including enzymes and chlorophyll, responsible for a multitude of physiological processes within the plant. Nitrogen plays an intermediary role in the utilization of phosphorus, potassium, and other elements within plants, implying a synergistic relationship with these elements (Brady and Weil, 2007). Young maize plants exhibit rapid phosphorus absorption, promoting vigorous root growth. Phosphorus also has the potential to accelerate fruit ripening, especially when excessive nitrogen is present in the soil (Onasanya *et al*., 2009). Plants suffering from phosphorus deficiency exhibit stunted growth, evident through dark green leaves. Distinct purple traces can emerge along leaf margins, veins, and stems, often extending across the entire leaf blade. This reddish discoloration is most noticeable during the initial stages of the plant's growth (Bromley and County, 2010). Potassium has a significant contribution in maintaining healthy green foliage, optimizing root growth, and facilitating overall development, ultimately leading to improved yield (Bromley and County, 2010).

Foliar fertilization of maize

When fertilizers are introduced into the soil, there is no guarantee of effective nutrient absorption by plants, potentially leading to wastage of active components (Yayock *et al*., 1988). Therefore, the availability of nutrients applied to the soil is critical. Soil characteristics can further hinder the efficacy of soil-applied fertilizers, particularly for certain micronutrients like Zn, Fe, Mn, and Cu, which may precipitate in insoluble forms within alkaline soils (Gooding and Davis, 1992). The availability of active ingredients from soil-applied fertilizers to plant roots is dependent on soil moisture, as nutrients must be solubilized before they can be absorbed by roots (Abbas and Ali, 2011). In contrast, foliar feeding offers an advantageous solution for supplying essential nutrients to crops, particularly when soil nutrients remain out of reach due to plant stress or adverse soil conditions. Nutrient uptake through leaf stomata is faster compared to root absorption, making it an efficient approach to promptly rectify plant nutrient deficiencies. For example, iron deficiency in calcareous soils can be remedied through foliar application of ferrous sulfate or iron chelate solutions, which prove more effective than soil-based iron sources (Girma *et al*., 2007). Apart from its remedial potential, foliar nutrient application provides a substantial quantity of essential nutrients to fortify the plant's immune system and offer protection against pests and harmful bacteria (Natrasol, 2013). Research has indicated that the use of foliar-applied NPK can enhance grain yield in maize (Ghaffari *et al*., 2011). In Ghana, foliar feeding is relatively novel and is primarily limited to the application of micronutrients on select vegetable crops such as chili peppers and tomatoes (Asumadu *et al*., 2012).

Impact of foliar micronutrients on grain yield

Micronutrients play a vital role in enhancing plant nutrition and overall productivity. Typically, agricultural soils exhibit deficiencies in micronutrients such as zinc, boron, iron, and copper leading to deficiencies in plant. (Khan *et al*., 2019). Maize, especially during the critical V4 to VT growth stages characterized by high nutrient demands, may encounter a situation where its nutrient requirements surpass available supply (Stewart *et al*., 2020). To address this, the practice of foliar application of micronutrients during this period to supplement soil nutrient availability is commonly employed (Fageria *et al*., 2009). Certain cereal crops have demonstrated positive responses to the application of both macro and micronutrients throughout their growth stages, leading to enhanced overall yield (Khan *et al*., 2019). Despite their lower quantities, micronutrients like zinc, copper, iron, manganese, boron, molybdenum, and chlorine are as indispensable as major nutrients such as nitrogen, phosphorus, and potassium for plant health and development (Khan *et al.*, 2019).

A recent study by Stewart *et al.* in 2020 also examined the influence of foliar micronutrients on maize yield. The results indicated that, on average over three years, there were no significant yield increments attributable to any specific micronutrient product. However, specific conditions revealed visual signs of deficiency, exceeding critical plant tissue levels, and foliar iron supplementation notably improved grain yield. In cases where confirmed micronutrient deficiency was absent, yield responses were less predictable due to variations in prior soil and plant nutrient concentrations. Stewart *et al.* (2020) also emphasized that certain combinations of foliar treatments involving boron, manganese, zinc, and iron exhibited significant yield increases. The relative immobility of iron and most micronutrients within plant tissue, as indicated by Bryson *et al.* (2014), precludes the regreening of untreated new growth leaves. This finding aligns with established deficiency correction theories (Shapiro *et al.*, 2003). However, the concentration of iron in both plant and soil alone did not consistently predict grain yield response to foliar iron. A similar outcome was observed in a hydroponics study evaluating foliar iron conducted by Ward and Ward (2015). It is essential for micronutrient supplementation to yield predictable and economically significant grain yield improvements that can offset the associated costs, a requirement not fully met by the current trials.

Crop responses to foliar fertilizers

Foliar fertilization provides a quicker mechanism for nutrient absorption, facilitating rapid remedy of identified deficiencies compared to soil application (Fageria *et al.*, 2009). Under favorable weather conditions, crops respond to foliar fertilizer shows within a shorter span (Niu *et al.*, 2021). Therefore, the impact of foliar sprays on plants is often transient, necessitating repeated treatments in cases of severe nutrient scarcity. While soil application proves effective for both macro and micronutrients, foliar application demonstrates enhanced efficacy, particularly for micronutrients (Niu *et al.*, 2021). This approach proves more resource-efficient for certain immobilized soil nutrients, such as iron. During the initial growth phase, foliar fertilization exhibits superior absorption, capitalizing on the incipient establishment of plant roots compared to soil application. However, achieving an optimal leaf area index (LAI) to ensure efficient spray interception remains pivotal for foliar application (Loupassaki *et al.*, 2002). For instance, a leaf LAI of 2-4 has been established as sufficient for wheat (Gooding and Davies, 1992). Excessive salt solution concentration could induce foliage scorching, a risk less prominent in soil application scenarios (Fageria *et al.*, 2015). Wind greatly contributes to the variability in spray deposition during foliar fertilization, underscoring the importance of precautions on windy days to ensure even fertilizer distribution. Moreover, the application of fertilizers as sprays provides the opportunity to concurrently administer other agrochemicals through tank mixes, resulting in labor, equipment, and energy savings (Gooding and Davies, 1992). The efficacy of foliar absorption at higher rates is widely believed to depend on elevated relative humidity, as rapid drying can lead to crystallization on leaf surfaces (Gamble and Emino, 1987). The benefits of foliar application extend beyond enhanced nutrient uptake efficiency and reduced production costs; it also mitigates the runoff of soil-applied phosphorus, a major contributor to the eutrophication of lakes and streams (Sharpley *et al.*, 1994). Micronutrients, necessitating minute quantities, exhibit more uniform distribution through foliar application compared to soil methods (Fageria *et al.*, 2009).

Conclusion

It can be concluded that using foliar fertilizer in addition to the soil-based fertilizer can have a positive effect on the yield of maize including its biomass. Foliar application of fertilizers improves the absorption of nutrients that are immobile and difficult for plant root absorption, thus reducing the plant deficiency symptoms. It can also be used as a remedy for drought affected maize at the vegetative stage to maximize yield. However, there is the need for a socio-economic analysis to identify the difference between the yield obtained and the cost of the foliar fertilizer.

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