Secondary and micronutrient inclusion in fertilizer formulation impact on maize growth and yield across northern Ghana

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Cogent Food & Agriculture (2019), 5: 1700030
SOIL & CROP SCIENCES | RESEARCH ARTICLE

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J. X. Kugbe1*, R Kombat1 and W Atakora2

Abstract: Though secondary and micronutrients are known to improve crop production, their inclusion in fertilizer formulation has received minimum attention in efforts aimed at increasing maize production in northern Ghana. In this study, Sulphur, Boron, and Zinc were included in NPK formulations at different rates in northern Ghana. The experiment was a single factor, consisting of NPK 15-15-15 applied at rates (kg/ha) of 60-40-40, NPK 15-15-15 at rates of 90-60-60, NPK 15-15-15 at 100-40-40, NPK 11-22-21 + 5S + 1B + 1Zn at 60-40-38 + 9 + 1.8 + 1.8, NPK 11-22-21 + 5S + 1B + 1Zn at 90-60-57 + 14 + 2.7 + 2.7, NPK 11-22 21 + 5S+1B+1Zn at 100-40-38 + 9 + 1.8 + 1.8, NPS 14-31-0 + 95 + 1B + 1Zn at 60-40-0 + 11.6 + 1.3 + 1.3, NPS 14-31-0 + 95 + 1B + 1Zn at 90-60-0 + 17.4 + 1.9 + 1.9, NPS 14-31-0 + 95 + 1B + 1Zn at 100-40-0 + 11.6 + 1.3 + 1.3 and no fertilization. Treatments were randomly laid out in four farms. Urea at respective rates was applied at 6 weeks after planting. Data analyzed on growth and yield parameters at 5% probability showed that significantly higher growth and yield were recorded with the inclusion of secondary and micro-nutrients ($P < 0.05$). NPK 11-22-21 + 5S + 1B + 1Zn at 90-60-57 + 14 + 2.7 + 2.7 increased yield by 30% (mean: 3330 kg/ha) compared to the standard yield from NPK 15-15-15 at 90-60-60 (mean: 2585 kg/ha) which consisted solely of primary nutrients. Also, NPS 14-31-0 + 95 + 1B + 1Zn at 100-40-0 + 11.6 + 1.3 + 1.3 followed with yield increment of 26% (mean: 3252 kg/ha), with the zero-control treatment giving the lowest yield (mean: 356 kg/ha). While the study confirms the need for use of fertilizer in maize production across northern Ghana it demonstrates the need for secondary and micronutrient inclusion in fertilizer blends for soils of Northern Ghana.

ABOUT THE AUTHOR

J. X. Kugbe is a soil scientist with the Department of Agronomy, University for Development Studies, Ghana. Over the years, Dr Kugbe has researched into soil chemistry with particular interest in plant nutrition and fertilization. His research findings show the need to incorporate specific micro nutrients as essential components in fertilizer formulation for major cereals including maize and rice. His other research interests range from greenhouse gas emissions under cropping systems, modelling and soil mineralogy.

PUBLIC INTEREST STATEMENT

In the low-income and resource-poor farming communities of northern Ghana where the bulk of maize is produced, farmers hardly include sulphur and micronutrients in fertilization. This study shows that the inclusion of sulphur, boron, and zinc could increase maize yield by up to 29% compared to non-inclusion. Whilst studies of secondary and micronutrient inclusion remain unavailable for decision-making, findings from this study provide bases for their inclusion in fertilizer formulation across the region.
1. Introduction

While many other cereals are used as food, maize is the most widely consumed in northern Ghana. Low soil fertility and low application of external inputs are two major factors that affect the productivity of maize and which accounts for the low yield of the crop (Mangnus & van Westen, 2018). Soils of the major maize growing areas are low in organic carbon (<1.5%), total nitrogen (<0.2%), exchangeable potassium (<100 mg/kg) and available phosphorus (<10 mg/kg) (Kugbe & Issahaku, 2015). The low nutrient content of the soils necessitates the need for external nutrient input in order to increase productivity. Improving maize yields through increased soil productivity of the northern soils can be achieved by external inputs of nutrients into the nutrient-poor soils, which may be in the form of inorganic, organic or bio-fertilizers. Across these resource-scarce communities, organic and bio-fertilizers are scarce – a reason for which such nutrient inputs are sparingly used. The most sourced of inorganic fertilizers are commercial mineral fertilizers, which farmers can easily access on the open market.

From 1969 to 1972, fertilizer recommendations were made for maize and other crops. Now, soil conditions have changed over the years and the old recommendations are not most efficient today. Hence, the need to update fertilizer recommendations for maize in the northern savanna agro-ecological zone (AEZ) of Ghana. Over the years, the use of NPK fertilizers has been the primary means of nutrient replenishment. This is understandable as NPK remains the most important nutrients required for crop production (Chukwuka, Ajala, Nwosu, & Omotayo, 2015). Sole application of NPK has helped to increase maize yield and contributed to food security. However, some room remains for further yield increment particularly for northern Ghana where the average yield of 1.5 t/ha is below the global average of 4.9 t/ha (Yigermal, Nakachew, & Assefa, 2019).

It has been postulated that the inclusion of secondary nutrients such as sulphur (S) and micronutrients such as boron (B) and Zinc (Zn) in fertilizer blends could increase maize yield sharply (Sutar, Pujar, Aravinda Kumar, & Hebsur, 2018). This postulate has not been confirmed nor denied in the northern savannah zone of Ghana. In view of this, fertilizer blends in northern Ghana remain primarily of N, P and K, limiting possible yield increments attributable to secondary and micro-nutrient inclusion. The need arises therefore to understudy the growth and yield increment of fertilization that can be attributed to secondary and micronutrient inclusion in fertilizer formulation for northern Ghana. The objective in this research was therefore to evaluate the productivity of sulphur (a secondary nutrient), boron and zinc micro-nutrient inclusion in fertilizer formulation for maize production in northern Ghana.

2. Materials and methods

2.1. Study area

The study was carried out at Akukayilli in the Tolon district of Northern Ghana in the 2017 and 2018 rainy seasons. The site is located about 16 km west of Tamale and lies on latitude N 09º 24’ 15.9” and longitude W 001º 00’ 12.1”. The area has a uni-modal rainfall pattern averaging about 1100 mm annually. The uni-modal rainy season occurs between May and October but is irregular with dry spells during the rainy season. Peak rainfall occurs in August and September. Following the rains are long periods of dry Harmattan weather from November to April. The region is subject to extreme bushfire outbreaks during the dry season (Kugbe, Fosu, Tamene, Denich, & Vlek, 2012). The landscape is characterized by gentle sloping areas with rock outcrops and stony areas. Lixisols are the main soils of the area. The soils range from sandy to laterite and are generally of poor nutrient status (Table 1).

They are typically extremely low in organic matter (generally less than 1% compared to well-structured soil levels of 3.5% found in southern Ghana). They are particularly noted for their low
Table 1. Physico-chemical characteristics of soils of the study area. Physico-chemical properties were determined based on the procedure used by Kugbe and Issahaku (2015)

| Depth (cm) | pH (1: 1) | % OM | %N | P (mg/kg) | Ca | Mg | K | Na | TEB | ECEC (cmol+/kg) | Texture |
|-----------|-----------|------|----|-----------|----|----|---|----|-----|----------------|---------|
| Farm 1    | 5.9       | 0.6  | 0.03 | 14.5      | 1.6| 1  | 0.2| 0.1| 2.9 | 2.5             | LS      |
| Farm 2    | 5.8       | 0.5  | 0.05 | 9.2       | 2.9| 1.7| 0.2| 0.1| 4.9 | 5.1             | SCL     |
| Farm 3    | 5.6       | 0.4  | 0.03 | 12.5      | 1.9| 1.4| 0.1| 0.1| 3.5 | 3.7             | SCL     |
| Farm 4    | 5.4       | 0.4  | 0.03 | 10.6      | 1.5| 0.8| 0.1| 0.1| 2.5 | 3.6             | SCL     |
levels of available nitrogen and phosphorous that require NPK application to realize a meaningful yield. Poor soil fertility combined with erratic rainfall is common concern to farmers in the prevailing rain-fed system. Natural vegetation across the area include grasses, shrubs, and trees. Common herbaceous plant species include those of the family Rubiaceae (e.g. *Diodia scadens* Sw.) and Acanthaceae (e.g. *Monechma ciliatum* Jacq.). Major grasses include those of the family Poaceae/Graminaea (e.g. *Digitaria horizontalis* Wild, *Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult, *Schizachyrium exile* (Hochst.) Pilger, *Andropogon gayanus* Kunth, and *Dactyloctenium aegyptium* P. Beauv.). Tree species include those of the family Combretaceae (e.g. *Combretum lamprocarpum* Diels, and *Terminalia avicennoides* Guill. & Perr.), Leguminosae-Mimosoideae (e.g. *Entada africana* Guill. & Perr.) and Rubiaceae (e.g. *Gardenia ternifolia* var. goetzei (Stapf & Hutch.) Verdc. (Stapf & Hutch.) Verdc.). Shrub species include the family Euphorbiaceae (e.g. *Securinega virosa* (Roxb. ex Willd.) Pax & Hoffm.) and Fabaceae (e.g. *Chamaecrista mimosoides* (Linn.) Greene). Agriculture predominates the economic activities of the people. Cultivated food crops include yam (*Dioscorea cayenensis* ssp. rotundata (Poir.) Lam.), corn (*Zea mays* L.), cowpea (*Vigna unguiculata* (L.) Walp.) and cassava (*Manihot esculenta* Crantz) (Kugbe et al., 2012).

### 2.2. Experimental design

The experiment was a single factor experiment laid out in a Randomized Complete Block Design with four replicates. Field sizes of 59 m × 10 m were demarcated on 4 farms. Plot sizes of 10 m X 5 m were used and each farm served as a block. One (1) m alley was left between treatment plots.

Primary, secondary and micronutrient formulation and rates were used as treatments and included:

1. NPK 15-15-15: this is the most common fertilizer formulation in the Ghanaian market with the accepted application rate of 90-60-60 kg/ha for maize production, using urea for N top-up.
2. NPK 11-22-21 + 5S + 1B + 1Z: This fertilizer formulation is one of the trial fertilizers whose efficacy and performance is anticipated to impact maize growth and productivity. The inclusion of sulphur as a secondary macronutrient, boron and zinc as micronutrients and higher levels of P and K was anticipated to impact positively on maize growth and yield.
3. NPS 14-31-0 + 5S + 1B + 1Z: This fertilizer formulation was anticipated to also impact on growth and yield of maize as in formulation 2. The difference between formulation 2 and 3 is the absence of K₂O in formulation 3 and a higher level of P₂O₅ in formulation 3.

The combination of treatments and fertilizer formulations used as treatments is in Table 2.

### 2.3. Agronomic practices

On each farmer’s field, Wang Daata maize variety was planted at a rate of four seeds per hill and thinning out to two plants per hill after germination. Planting was done at a spacing of 80 cm between rows and 40 cm within rows. First fertilizer (NPK and NPS) was applied two (2) weeks after planting and urea application as top-up fertilizer was done six (6) weeks after planting. All good agronomic practices in maize production were duly followed. Weed control was done manually by hoeing every 3 weeks, starting from the second week after planting. There were no pests nor disease control as no incidences were observed.

### 2.4. Plant data collection

Sampling for growth and yield data were done at 2nd, 4th, 6th, 8th, 10th, 12th week after planting and after harvest of the maize crop, respectively. Ten (10) plants on each plot were randomly tagged taking into consideration the border effect of each plot for the following growth and yield parameters.
2.4.1. Plant height
Plant height measurements were taken from the second (2nd) to the twelfth (12th) week after planting. Data were taken at two (2) week intervals with the use of a measuring tape. Dimension was taken from the ground level to the base of tassel. The average for each plot was then computed and calculated.

2.4.2. Leaf Chlorophyll
A similar procedure as used by Abubakar, Manga, Kamara, and Tofa (2019) was employed in Chlorophyll determination at peak flowering. A Minolta chlorophyll meter (SPAD 502, Illinois, USA) was used to take these data on the 10 tagged plants after which the average was calculated for each plot. The SPAD readings were taken at two-thirds of the distance from the leaf tip (without the midrib) towards the stem of the ear leaf.

2.4.3. Stover weight
At harvest, 30 plants were randomly selected from each plot. The above-ground weights were air-dried and subjected to a 60°C oven drying for 48 h. The weight of these plants was determined using the electronic weighing scale. The average measurements of these plants were converted to the weight of stover in kg/ha.

2.4.4. Cob weight
The cobs of each tagged crop on each treatment plot were air-dried and then oven-dried at 60°C for 48 h to eliminate moisture. The weight of oven-dried cob was then estimated for 1-ha field in kg/ha.

2.4.5. Grain yield
After harvesting, cobs were manually threshed on plot bases. Harvesting of plots was done separately in accordance to each treatment. De-husking, threshing and winnowing were manually done. Threshed grains were air-dried and oven-dried to 13% moisture content by weight. The weighed grains were converted into weight per unit area (kg/ha).

3. Data analysis
All the data collected from the field were analysed using analysis of variance (ANOVA) in GenStat Statistical package 12th edition. The treatment means were separated and compared using the Least Significant Difference (LSD) at 5% level of probability.
4. Results and discussion

4.1. Plant height, leaf chlorophyll and stover weight

Prior to fertilizer treatments, the plant heights were statistically similar (P > 0.05) at the 2nd week after planting (mean = 0.974). However, the plant heights increased considerably after the treatments were applied and varied significantly among the fertilizer regimes (Figure 1).

The differences in plant height between the nutrient regimes increased with growth and were greatest at 8 weeks after planting (WAP). NPK formulation 11-22-21 + micronutrients (SBZ) at 100-40-38 resulted in the tallest plants while NPK 11-22-21 + micronutrients (SBZ) at 90-60-57 were the next tall plants. NPK 15-15-15 at 90-60-60 were almost of the same height as NPK 11-22-21 + micronutrients (SBZ) at 90-60-57. As all conditions remain same except sulphur and micronutrient inclusion, the increase in plant height is attributed to the inclusion of S, B, and Z in the fertilizer formulation and confirms the findings of Sutar et al. (2018) and Njoroge, Otinga, Okalebo, Pepela, and Merckx (2018) who observed that inclusion of sulphur and micronutrients improved growth of the maize crop even in non-responsive soils.

At peak flowering, statistically significant differences in leaf chlorophyll between the different fertiliser regimes were observed (Figure 2(a)). Crops that received NPK (11-22-21 + S B Z) at 100-40-38 + 9 + 1.8 + 1.8 had high green pigments (chlorophyll) in their cells. NPK 15-15-15 at 90-60-60 and NPK (11-22-21 + S B Z) at 90-60-57 + 14 + 2.7 + 2.7 also recorded significantly high leaf chlorophyll contents.

Leaf chlorophyll is a key determinant of crop growth due to its influence on photosynthesis. The increase in leaf chlorophyll may have been due to the improved leaf chlorophyll content in plants that received NPK + secondary and micronutrients (S + B and Z). As shown by Daphade, Hanwate, and Gourkhede (2019), B and Zn as micronutrients enhance the availability of Primary and secondary nutrients to enable uptake by the crop. This shows that inclusion of micronutrients in NPK fertilizer grade (11-22-21) increased the photosynthetic activity due to high leaf chlorophyll reflecting in increased stover weight and yield of grains (Figure 3). The results show that the sole availability of N, P and K only, as found in primary NPK fertilizers, even at higher application rates may not be adequate for enhanced photosynthetic ability in maize production for the nutrient-poor soils of northern Ghana. The increase in leaf chlorophyll with the inclusion of Sulphur and micronutrients (S + B and Zn) to NPK fertilizer levels might also be due to uptake synergy as micronutrients are reported to enhance the availability of the other nutrients (Daphade et al., 2019).

The inclusion of secondary and micronutrients in fertilization also had a highly significant effect (p < 0.001) on the stover weight (Figure 2(b)). NPK 11-22-21 + S B Z at 90-60-58 recorded the highest weight value with the control treatment recording the lowest. The results show the need
for sulphur and micronutrient inclusion in chemical fertilizer formulation as proposed by Yigermal et al. (2019) and further agree with Olowookere, Oyerinde, and Malgwi (2017) who reported from their findings that micronutrient application enhanced the yield of maize stover and quality.

4.2. Cob weight and grain yield
A similar finding of secondary and micronutrient effect as in stover weight was observed for cob weight (Figure 3(a)). However, the rate of application greatly had an influence on the cob weight. NPK 11-22-21 at 90-60-57 recorded higher cob weight that significantly differed from all other treatments and...
rate of application. NPS 90-60-0 + 95 + B + Z also recorded high weights but was at the same level with NPK 11-22-21 at 100-40-38 which was high in weight than all application rates of NKP 15-15-15.

Total grain yield was significantly ($p < 0.001$) influenced by primary, secondary and micronutrient application regimes. Application of NPK 11-22-21 at 90-60-57 statistically gave higher yields (Figure 3(b)). NPK 11-22-21 at 100-40-48 and NPS 90-60-10 + B Z were statistically similar in yield, recording the next highest. NPK 15-15-15 at 90-60-60 and at 100-40-40 recorded lower yields compared with the former while NPK 15-15-15 at 60-40-40 recording low yield next to the control (no fertilizer) treatment.

To the resource-poor farmer, grain yield is the most economic end result of morphological and physiological processes that occur during the growth and development of the maize plant. As grain yield generally increased with increasing application rate of NPK + micronutrients, the rate of primary nutrient application, irrespective of the nutrient formulation must be a critical determinant of yield in the region. NPK 11-22-21 + 5S + 1B + 1Zn at 90-60-57 + 14 + 2.7 + 2.7 increased yield by 29% (mean: 3330 kg/ha) compared to the standard yield from NPK 15-15-15 at 90-60-60 (mean: 2585 kg/ha). Also, NPS 14-31-0 + 9S + 1B + 1Zn at 100-40-0 + 11.6 + 1.3 + 1.3 followed with yield increment of 26% (mean: 3252 kg/ha) over that of NPK 15-15-15, with the zero-control treatment giving the lowest yield (mean: 356 kg/ha). While sole primary NPK application increased maize yield by 7-folds in the nutrient-poor soils, inclusion of S, B and Zn increased maize yield to almost 10-fold. The better grain yield with NPK 11-22-21 + micronutrient (S + B and Zn) at 90-60-57 + 14 + 2.7 + 2.7 rate of application could be attributed to the inclusion of S and the micronutrients (S, B and Zn) in the NPK fertilizer blend which resulted in enhanced nutrient availability, better growth and productivity. Besides, the reduction in grain yield in the control plots that received no fertilization might have been due to deficiency of important nutrients including N, P and K. This result is similar to the findings of Kihara et al. (2017), Njoroge et al. (2018) and Lisuma, Semoka, and Sem (2016), who revealed that grain yield could be significantly increased through secondary and micronutrient addition. The increase in grain yield due to secondary and micronutrient inclusion relative to the control plot could be due to improvement in soil nutrient deficiency and imbalances in the area. Sulfur is required by plants for synthesis of major metabolic compounds such as glutathione, proteins and amino acids and sulfo-lipids required for healthy crop growth (Qahar & Ahmad, 2016). While inclusion of Mg as a secondary nutrient in NPK formulation may have comparatively low effect on maize growth and yield, inclusion of sulphur in plant nutrition is known to better enhance and synergize the uptake of other essential nutrients like N, thereby increasing both N use and S use efficiency and promoting the growth of the plant (Fismes, Vang, Guckert, & Frossard, 2000). Like sulphur, boron increases protein contents in the plant and also plays vital roles in cell wall division, synthesis, elongation and nucleic acid metabolism that translates into rapid plant growth (Tahir et al., 2012). Boron and zinc also work in synergy with hormones and enzymes that perform various functions in the metabolism of carbohydrate and protein and efficient water use in the crop (Ceyhan et al., 2008; Dell & Huang, 1997; Gupta & Solanki, 2013; Rudani, Vishal, & Kalavati, 2018). Under the prevailing rainfed system which is sometimes marked by draught, enhanced water use efficiency is critical for the development of the crops. These explain the observed better growth in plants that received boron and zinc micronutrients compared to those that did not (Figures 1 and 2). As noted by Irfan et al. (2019), a synergy that is generated in phosphorus uptake by B, enhances crop production even under P deficient soils upon boron addition. Zinc plays roles in resistance to heavy metal concentration (Rizwan, Ali, Rehman, & Maqbool, 2019), diseases and enhances photosynthesis and carbohydrate accumulation (Rudani et al., 2018). The combined effect of sulphur, boron and zinc may have synergistically resulted in the observed better growth and high yields in fertilizer formulations that included all three nutrients.

The highest rate of NPK formulation did not give, correspondingly, the greatest grain yield when compared to secondary and micronutrient inclusion. The results show that beyond some levels of
NP and K fertilization, inclusion of secondary and micronutrients could result in substantial increases in maize productivity. The finding is in agreement with that of Njoroge (2018).

5. Conclusion
Inclusion of S as a secondary nutrient, together with boron and zinc as micronutrients in NPK fertilizer formulation improved maize crop growth and grain yield in northern Ghana. Yield increases of up to 29% were recorded through inclusion of these nutrients with primary NPK compared to sole application of primary NPK fertilizers. While the sole application of NPK to the nutrient-poor soils resulted in seven (7) fold increases in yield compared to unfertilized fields, the inclusion of sulphur, boron and zinc resulted in almost 10-fold increases in yield. The increases in yield due to S, B and Zn inclusion are attributable to enhanced synergy in growth-promoting factors— including protein and amino acid synthesizing properties of S, enhanced physiological and environmental tolerance to diseases, water stress, and improvements in P and N-uptake that promotes crop growth. Sulphur, boron and zinc should be considered for inclusion in chemical fertilizer formulation for maize production in northern Ghana.

Funding
The authors received no direct funding for this research.

Competing interests
The authors declare no competing interests.

Author details
J. X. Kugbe1
E-mail: joekugbe@yahoo.com
R Kombat2
E-mail: richardkombat@outlook.com
W Atakora2
E-mail: willatnet@hotmail.com

1 Department of Agronomy, University for Development Studies, P. O. Box TL1882, Nyankpala Campus, Nyankpala, Ghana.
2 Savanna Agricultural Research Institute, Nyankpala, Ghana.

Cover image
Source: Author.

Citation information
Cite this article as: Secondary and micronutrient inclusion in fertilizer formulation impact on maize growth and yield across northern Ghana. J. X. Kugbe, R Kombat & W Atakora, Cogent Food & Agriculture (2019), 5: 1700030.

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