

Evaluation of Micronutrient Coated Urea and Sulphur on the Growth and Yield of Sorghum (*Sorghum bicolor* L) in Sudan Savanah Agro Ecological Zone of Nigeria

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ABSTRACT

Field trials were carried out at Federal College of Agricultural Produce Technology Research farm at Kura and Tokarawa to evaluate the effect of micronutrient-coated urea and Sulphur on the growth and yield of sorghum (*Sorghum bicolor* L.) in the Sudan Savanna ecological zone of Nigeria during the 2022 and 2023 wet seasons using a randomized complete block design (RCBD) with three replications. Treatments consisted of varying combinations of Boron (B) and Zinc (Zn) micronutrient-coated Urea at two rates (1.25 and 2.5 kg ha⁻¹) applied singly and in combination with Sulphur (20 and 40 kg ha⁻¹). Data were collected on plant height, leaf area index, crop growth rate, net assimilation rate, 100-grain weight and grain yield to evaluate the influence of Sulphur and micronutrient coated Urea on growth and yield of Sorghum in the study area. Results revealed from the study indicated that all measured parameters were significantly ($p < 0.05$) influenced by micronutrient and Sulphur treatments across locations and seasons. The combined application of 2.5 kg Boron-coated urea + 40 kg S ha⁻¹ and 2.5 kg Zn-coated urea + 40 kg S ha⁻¹ consistently produced the highest plant height, leaf area index, crop growth rate, and grain yield compared to the control. The research therefore recommended the use of micronutrients-coated urea in combination with Sulphur for improved sorghum productivity and efficient nutrient use.

Keywords: Micronutrients, Coated urea, Boron, Sulphur, Assimilate, Zinc

INTRODUCTION

The origin and early domestication of sorghum was said to have been done around 5000 to 8000 years ago in northeastern Africa or at the Egyptian-Sudanese border (Mann et al. 1983). Sorghum originated in Africa, found there is the largest diversity of cultivated and wild sorghum (de Wet 1977). The secondary center of origin of sorghum is the Indian sub-continent, with evidence for early cereal cultivation discovered at an archaeological site in western parts of Rojdi dating back to about 4500 before 1950 A.D. Sorghum was described firstly by Linnaeus in 1753 under the genus *Holcus*. Moench defined the genus sorghum to contain two species in 1794 (Celarier 1959). Since then, sorghum has undergone many taxonomic treatments to become the genus recognized today. Sorghum is the world's fifth most important cereal crop after rice, maize, wheat and barley, (Ingle et al., 2023), Nigeria's bulk of sorghum production is derived from the Northern Guinea and Sudan/Sahel ecologies of Northern Nigeria. Sorghum is regarded as a traditional food crop in this agro-ecologies. One of Nigeria's most important agro-ecological zones is the Sudan Savanna, which spans a large area between the

Sahel Savanna to the north and the Guinea Savanna to the south. It covers roughly 25% of the nation's land area and includes states like Kano, Jigawa, Katsina, Zamfara, Sokoto, Bauchi, and portions of Yobe (Aduayi et al., 2020; FAO, 2021). The region is known for its semi-arid climate, which includes a long dry season that lasts six to eight months, a mean annual rainfall of 500 to 900 mm, and a clear unimodal rainfall pattern (Usman et al., 2019). Sorghum is preponderantly grown in semi-arid and arid areas, which received less amount of rainfall (Hadebe et al. 2017). Sorghum tolerate drought, grows well in altitudes between 800- 2000 meters above sea level. Sorghum does well on moist soils with a temperature of 150 or higher at 10cm depth. It is a short day and long night crop. Photoperiod and temperature are very important in the growth and development of sorghum (Prasad 2021). In Nigeria, specifically the Sudan and Sahel Savannas, sorghum is a major staple cereal crop that is used for food, fodder, and as a raw material for industrial processes like the production of malt and ethanol (Aliyu et al., 2018). Sorghum is a crop that has multiple uses around the globe as grain, for sweet stem, for animal feed, as pasture, fodder, fibre, source of fuel, alcoholic beverages, as well as building materials (Hariprasanna, 2015; and Bollam, 2011). Sorghum plays important role in food security due to its ability to survive in harsh conditions and its nutritional quality (Akin 2022). The grain is used as a staple food for a lot of people in arid and semi-arid areas in the tropics and as a gluten free food product in other regions (Belton, 2004). Nitrogen is known to be the major constraint to increased sorghum production in Nigerian savanna especially Sudan savanna which is characterized by low soil total nitrogen and soil organic matter. Nitrogen is the most limiting nutrient under continued cropping and the major constraint to increased sorghum production in the Savanna zone of Nigeria (Bagayoko et al., 2000). Sulphur deficiency in crops is acknowledged as a critical limiting factor not only for growth and seed yield but also for the quality of the final products. This is due to Sulphur being a key component of several vital compounds, including cysteine, methionine, coenzymes, thioredoxin, and sulfolipids. Research has indicated that the application of Sulphur modifies the amino acid profile, resulting in a higher proportion of Sulphur-containing amino acids such as cysteine and methionine (Singh, 2003). In Northern Nigeria, sorghum is consumed in various forms, including as a Tuwo (a thick porridge made from dry-milled, non-fermented grain flour eaten with soup), Kunu or Ogi (flour paste made by wet milling after fermentation and cooked like a thin porridge), fermented pancakes and snack as roasted grain (Ega et al. 1992). The production and productivity of the crop is yet to be expounded in Nigeria for economic gains. The growth and yield of sorghum bicolor using micronutrients coated urea has not received adequate research attention especially in Nigeria. Thus, the use of micronutrients coated urea can bring about increase and sustainable food production to bridge the demand of the increasing human population. Consequently, the aim of the study is to evaluate the effect of micronutrients coated urea and Sulphur on the performance of sorghum in the Sudan savanna zone of Nigeria.

MATERIALS AND METHODS

EXPERIMENTAL SITE

The Experiment was carried out during the 2022 and 2023 rainy seasons at two locations, Federal College of Agricultural Produce Technology Research Farm Kura (11.7701° N, 8.4239° E) and Tokarawa (12.1924° N, 8.6284° E), Sudan-Savannah Ecological zone of Nigeria. Meteorological data comprising rainfall and temperature data for the periods covering the trials was collected. The climate of the two locations is characterized by two seasons: the wet season (June-October) and the dry season (November -May) with annual rainfall of 800 - 1000 mm. The mean annual temperature is about 19.7-26.4°C

SOIL SAMPLING

Soil samples were collected randomly from 3 points each at the two experimental sites, at a depth of 0-30cm using an auger and then bulked by sites, air dried, and analyzed before sowing. The physical and chemical properties of the soils were determined using standard procedures as described by Black (1965).

DESCRIPTION OF THE VARIETY

SAMSORG-46 (locally called Zabuwa) is one of the most prolific sorghum seed varieties in Nigeria, it is also called 12KNICSV. It is an early maturing variety (81-94 days). It can be planted in all ecological regions of Nigeria, though it does best in the Guinea, Sudan and Sahel Savannah regions of Nigeria. It has a potential yield of 3tons/ha and high iron content.

TREATMENTS AND EXPERIMENTAL DESIGN

The experiment consisted two levels of Boron (B) coated urea; (1.25kgBcoated urea, and 2.5kgBcoated urea), two levels of Zinc coated urea (1.25 and 2.5kg coated urea), two levels of Sulphur (20kg and 40kg). Their combinations and the control (0 fertilizer), making a total of 14 treatment combinations and the control. These were laid out in a Randomized Complete Block Design (RCBD) replicated 3 times.

TREATMENTS COMBINATIONS

1. Control
2. 1.25 Boron (B) coated urea
3. 2.5kg Zinc (Zn) coated urea
4. 1.25gk Zinc (Zn) coated urea
5. 20kg Sulphur
6. 40kg Sulphur
7. 2.5kg Boron (B) coated urea + 20kg Sulphur
8. 2.5kg Boron (B) coated urea + 40kg Sulphur
9. 1.25 Boron (B) coated urea + 20kg Sulphur
10. 1.25 Boron (B) coated urea + 40kg Sulphur
11. 2.5kg Zinc (Zn) coated urea + 20kg Sulphur
12. 2.5kg Zinc (Zn) coated urea + 40kg Sulphur
13. 1.25gk Zinc (Zn) coated urea + 20kg Sulphur
14. 1.25gk Zinc (Zn) coated urea + 40kg Sulphur

Plot size

Plot size is made-up of 4 ridges (3m x 3m= 9m²). The intra row spacing was 0.25m while the inter row spacing was 0.75m. the inner ridges were used for the measurements of growth and yield parameters while the two outer ridges served as discards. A distance of 1.0m was used to separate the replications and 0.25 to separate the plots.

CULTURAL PRACTICES

Land Preparation

The experimental field was cleared, harrowed and ridged where required according to treatment. Plot size is made-up of 4 ridges (3m x 3m= 9m²). The intra row spacing was 0.25m while the inter row spacing was 0.75m. the inner ridges were used for the measurements of growth and yield parameters while the two outer ridges served as discards. A distance of 1.0m was used to separate the replications while a discard of 0.5m was used to separate the plots in a replication.

Sowing

The crop was sown on ridges at spacing of 0.75m × 0.25m (53,200 stands ha⁻¹) and at a depth of about 0.03m

and a seed rate of 6kg/h-1 and later thinned to 1 plant per hole.

Fertilizer application

A full dose of recommended N (100kg/ha^{-1}), P_2O_5 (40kg/ha^{-1}) and K_2O (40kg/ha^{-1}) WAS applied across all the plots. The appropriate quantities of the micronutrients coated fertilizers treatment combinations were applied in 2 split doses; at 2 WAP and 5 WAP according to the design of the experiment.

Weeding

Glyphosate (Glycel) was applied using a Knapsack sprayer to control weeds before land preparation. The first weeding was at 2WAP (weeks after planting) just before first fertilizer application followed by second weeding at 5WAP before second urea application at both locations.

Pest and Disease Controls

Pest control was done with the use of a systemic pesticide Emamectin Benzonate 5% WDG (Caterpillar force) at 2 ltr/ha-1 and disease control was done using Cyperforce (Cypermethrin 10% EC) chemicals at 3ltrs/ha.

Harvesting

The grains were harvested manually using cutlass when the grains were matured and dried. The entire plants were cut, staked up and after drying the heads were removed for threshing. Threshing took place by putting the panicle in a sack and beaten with a stick gently to separate the grains from the head. After threshing, it was then winnowed to separate the grains from the chaff.

DATA COLLECTION

Three plants (3) were tagged randomly on the net plot in each plot and growth parameters were measured, averaged and recorded at 4, 8 and 12 WAS.

Plant height (cm2)

The height of 3 tagged plants were measured using a measuring tape from the ground level to the tip of the tallest from which the average height was calculated and recorded.

Leaf area index

Leaf area index was determined from the total number of leaves of each of the tagged plants from the net-plot. The length of the leaf blade from the base to the tip was multiplied by a factor (0.744) then divided by the area of land covered (Mohammed, 2007).

Leaf area (LA) is given by

$$L \times W \times 0.744$$

Where L= length of leaf

crop factor for sorghum=0.75

Leaf area index (LAI) is given by

LA/P

Where LA=leaf area (cm²)

P= ground area covered/plant

Net assimilation rate (NAR)

This is the increase in plant dry matter per unit of assimilatory material per unit of time. it was determined at 4 weeks intervals using the formula by Watson (1958).

$$NAR = \frac{W2-W1}{A2-A1} \times \frac{\text{Loge } A2 - \text{Loge } A1}{t2-t1} \text{ (g/m}^2\text{/wk)}$$

Where

W1 = plant dry weight at t1

W2 =plant dry weight at t2

A1 and A2 = leaf area at times t1 and t2.

100 Grain weight (g)

100 grains were counted and the weight was measured in kg-1 from each plot.

Grain Yield (ton/ha)

This was obtained by harvesting all the plants from the net plot and extrapolated to per ha⁻¹ basis.

DATA ANALYSIS

The data collected was subjected to analysis of variance (ANOVA) using (with GENSTAT 21st Edition) to determine the level of significance as described by Snedecor and Cochran (1967). The significant treatment means were compared using DMRT.

RESULTS AND DISCUSSION

Physical and Chemical Properties of the Soil of the Experimental Sites.

Table 1 shows the physical and chemical properties of the soils of the experimental sites. The average results of the soil analysis of the experimental sites indicated that the soils were sandy loam in texture with sand having average higher proportion of 52.30 in Kura and 56.40 in Tokarawa. Averagely pH of the soils was (6.4) at Kura and 6.3 at Tokarawa. Furthermore, grain sorghum has traditionally been grown on soils with pH above 6.5 (Mask, et al., 1988) Low levels of organic carbon (0.65–0.78kg⁻¹) was at Kura and higher at Tokarawa (1.09–1.12). The medium organic carbon content is an indication that the soil is fertile and well drained and is favorable for the cultivation of sorghum (Adepetu et al., 2014) Total nitrogen was lower at Tokarawa (0.21–0.26g kg⁻¹, and higher at Kura 0.35–0.39 g kg⁻¹). Available phosphorus was also lower 5.01–5.43 at Kura and higher at Tokarawa 5.62–5.82. Calcium composition was low at Kura 1.54–1.81 and 2.23–4.19 at Tokarawa. Content of Magnesium at Kura was 0.42–1.20 and Tokarawa was 0.67–1.12. However, the result of the soil analysis also showed that the trial sites have moderate potassium at Kura 0.19–0.26 and 0.23–0.21 at Tokarawa. Respectively low sodium and CEC were recorded at Kura 2.82–4.53 and Tokarawa 3.68–7.07.

Plant Height (cm)

Table 2 shows the effect of micronutrients coated urea (CTU) and Sulphur application on sorghum plant height across Kura and Tokarawa during the 2022 and 2023 wet seasons. At 4 weeks after sowing (WAS) plant height was relatively moderate at both locations, although significant differences among treatments were already evident. In Kura during both 2022 and 2023, the untreated control and sole Sulphur treatments (20kg S ha¹ and 40kg S ha¹) consistently significantly lowest plant height. However, treatments involving micronutrient coated urea either alone or in combination with Sulphur mostly belonged to higher significance group, and the best performance at this stage was particularly associated with Zn-coated urea combinations, especially 2.5 Zn CTU and its mixture with Sulphur. Similarly, trends were observed in Tokarawa where coated urea plus Sulphur treatments significantly outperformed the control and sole Sulphur treatments. And superiority of treatments such as 1.25BCTU+ 20 S and 2.5Zn CTU+ 40 S that result interaction between Sulphur and micronutrient-coated nitrogen accelerated early establishment and canopy development. During the season at 8WAS treatment effect became more pronounced across both years and locations in Kura the treatments combining coated urea with Sulphur produced significantly taller plants than sole application and the control treatment such as 2.5BCTU + 40S and 1.25 Zn CTU +20S.and consistently highest significance groups during 2022, while the control and sole Sulphur treatments remained statistically inferior. In 2023, although some variability occurred among coated treatments, the combined applications still maintained superiority over the untreated plots. Furthermore, at Tokarawa, the trend was even more distinct, as nearly all coated urea treatments and their combinations with Sulphur significantly highest statistical group, during both 2022 and 2023. Whereas the control treatment and sole Sulphur remained significantly lower. And at 12 weeks after sowing (WAS) in Kura during 2022, treatments involving Zn-coated urea combined with Sulphur, particularly 2.5 Zn CTU + 40S, significantly produced the tallest plants and occupied the highest statistical groups, while the untreated control and sole Sulphur applications was lowest and similar patterns were observed in 2023, where B-coated urea combinations with Sulphur achieved the best performance. Hence for in Tokarawa, almost all coated urea treatments combined with Sulphur achieved the highest statistical ranking during both years. And across all the sampling period the p value obtained were statistically highly significant across all year at different weeks after sowing except at 4 WAS in 2023 result show p value is 0.002 respectively.

Leaf Area Index

Table 3 shows the effect of micronutrients coated urea (CTU) and Sulphur application on sorghum leaf area index (LAI) across Kura and Tokarawa during the 2022 and 2023 wet seasons. The results revealed significant variations among the treatment at 4, 8, and 12 weeks after sowing (WAS). At 4WAS, treatments containing coated urea combined with Sulphur, particularly 2.5BCTU + 20kg S ha¹ and 2.5BCTU + 40kg S ha¹ was significantly produced the highest LAI at both Kura and Tokarawa and these treatments promoted rapid early canopy establishment and vigorous leaf expansion. Similarly, combinations involving zinc-coated urea with Sulphur, especially 2.5zn CTU + 20kg S ha¹ and 2.5zn CTU + 40kg S ha¹ also maintained relatively high LAI and were statistically comparable with best performing treatments in several instances. And treatments such as 2.5BCTU, 1.25BCTU, 2.5zn CTU and 1.25zn CTU generally produced intermediate LAI. Response showing that coated urea alone improved vegetative growth relative to the untreated plots. Conversely, the control treatment and sole Sulphur application (20 kg S ha¹ and 40 kg S ha¹) and these consistently resulted in the lowest LAI across both environments and seasons. At 8WAS the superiority of integrated micronutrient-coated urea and Sulphur treatments became more pronounced treatment that involving 2.5BCTU combined with either 20 or 40 kg S ha¹ consistently maintained the highest LAI to the top statistical groups across locations and years. Also, zinc-coated urea combined with Sulphur also performed competitively, particularly 2.5zn CTU + 20 kg S ha¹ and 2.5Zn CTU + 40 kg S ha¹ , also the intermediate was observed in treatments such as 1.25BCTU, 1.25Zn CTU and their Sulphur combinations that the lower micronutrient rates improved growth but were comparatively less effective than the higher application rates. The persistence of lower LAI in control

and sole Sulphur treatments throughout this stage confirm nutrient imbalance. Conversely, at 12WAS treatment differences remained significant, especially at Kura, where 2.5BCTU + 20kg S ha⁻¹ and 2.5BCTU + 40kg S ha⁻¹ continued exhibit the highest LAI and this sustained superiority that the combined treatments prolonged leaf retention and delayed senescence, and treatments involving zin-coated urea with Sulphur also maintained relatively high LAI, though slightly lower than the boron-coated urea combinations. The lower performance of sole micronutrient treatments and untreated plots at this stage reduced nutrient use efficiency and accelerated decline in canopy vigor. And among treatment at 4, 8, and 12 weeks after sowing (WAS), the probability values obtained $p < 0.001$ across almost all sampling periods except at Tokarawa 4WAS where p is 0.002 and these result show that treatment exerted strong and consistent influence on sorghum canopy development and vegetative growth.

Net Assimilation

Table 4 shows the effect of micronutrients coated urea (CTU) and Sulphur application on sorghum net assimilation rate (NAR) across Kura and Tokarawa during the 2022 and 2023 wet seasons. At 4WAS the treatment combination of 2.5BCTU + 40kg S ha⁻¹ significantly consistently produced the highest NAR across both locations and seasons. And result that as a combined supply of boron and Sulphur created a synergistic effect that enhanced chlorophyll formation. Similarly, treatments involving Zn CTU combined with Sulphur, particularly 2.5Zn CTU + 20 or 40 kg S ha⁻¹ also reveal comparatively high NAR and were frequently within the upper significance groups, however these showed that Zinc supplementation contributed positively to metabolic and physiological processes associated with leaf expansion. However, their performance was slightly lower than the 2.5B CTU + 40 kg S ha⁻¹ treatment, implying that boron may have exerted a relatively stronger influence on assimilate partitioning. But the control treatments consistently show the lowest NAR across locations and years, mostly occupying the least significant groups. While sole Sulphur applications (20 and 40 kg S ha⁻¹) remained statistically inferior to the coated urea micronutrient-coated urea substantially improved nutrient synchronization. Furthermore, 8 weeks after sowing (WAS) there were superiority of micronutrient-coated urea combined with Sulphur became more pronounced, most treatments involving BCTU and Zn CTU with Sulphur were within the highest statistical groups and particularly 2.5B CTU + 40 kg S ha⁻¹ which consistently maintained superior NAR performance across location and years. And the persistence of high NAR at 8WAS result that coated urea technology likely enhanced gradual nutrient release, minimized nutrient losses. Hence for the clustering of many micronutrients coated treatments within similar statistical groups at 8WAS has once adequate micronutrient and Sulphur nutrition been achieved sorghum plant attained relatively comparable assimilatory efficiency. Conversely, across both environments, Kura generally exhibited stronger treatment differentiation than Tokarawa, possibly due to difference in soil fertility status, moisture availability or nutrient dynamics between the two locations. However, the consistent superiority of integrated micronutrient-coated urea and Sulphur treatments across years and locations show the stability and effectiveness of the technology under varying agro-ecological conditions.

100 Grain Weight

Table 5 shows the result on the effect of micronutrients coated urea and Sulphur on 100 grain weight of sorghum across Kura and Tokarawa during the 2022 and 2023 wet seasons revealed significant variations among the treatments. At Kura, treatments involving Zn-coated urea, particularly 2.5 Zn CTU and the combinations of micronutrients with Sulphur, consistently produced superior or comparable 100 grain weight but in 2022, 2.5 Zn CTU, 1.25BCTU + 20 S, and 1.25BCTU + 40 S were among the best performing treatments with the highest statistical groups. While several other micronutrient combinations fell within intermediate, during 2023, nearly all micronutrient coated urea treatments, either applied singly or combined with Sulphur belonged to the same statistical group. Similarly, at Tokarawa the combined application of coated urea and Sulphur significantly enhanced 100 grain weight relative to the control, in 2022, 2.5BCTU + 40S S significantly produced the highest

grain weight and was solely grouped. And treatments containing Zn coated urea and moderate Sulphur supplementation also performed well, occupying intermediate statistical groups while the control remained significantly lower. In 2023, the superiority of combined micronutrient and Sulphur treatments became more evident as 2.5BCTU + 40 S and 2.5 Zn CTU + 40 S attained the highest statistical grouping. Whereas the control and sole Sulphur treatments remained at the lowest.

Grain Weight per hectare kg

Table 6 shows the result on grain weight per hectare of sorghum showed that the application of micronutrient-coated urea combined with Sulphur significantly improved grain yield at both Kura and Tokarawa across the 2022 and 2023 wet seasons. Generally, the superiority of the higher micronutrient-coated urea rate (2.5 kg coated urea) combined with 40kg S ha¹ was consistently evident in both locations and years. Across the two seasons, treatments involving 2.5BCTU + 40 S and 2.5Zn CTU + 40 S ha⁻¹ consistently produced the highest grain weight and were statistically grouped in the highest significance treat particularly at Kura. The control treatment consistently results in the lowest grain weight across locations and seasons and falling into the lowest significance groups. Similarly, sole Sulphur applications at 20 and 40 kg S ha¹, although slightly better than the control, remained significantly inferior to treatments receiving micronutrient-coated urea this outcome resulted that Sulphur alone not sufficiently meet the nutrient requirement for optimum sorghum grain production without complementary micronutrient enhancement. Furthermore, intermediate grain weight was generally obtained from treatments containing lower micronutrient-coated urea rates (1.25BCTU and 1.25Zn CTU) either alone or combined with 20 kg S ha¹. At Tokarawa the yield response appeared more pronounced than at Kura, as reflected by wider statistical separation among treatments. The treatment combinations involving 2.5BCTU + 40 S and 2.5Zn CTU + 40 S ha⁻¹ result significantly clear superiority, while treatments such as 2.5BCTU, 2.5Zn CTU, and their combinations with 20 kg S ha⁻¹ produced moderate to high grain weights. But this stronger response at Tokarawa may be associated with greater micronutrient deficiency.

Table 1: Physical and Chemical Properties of Soils (0-30cm) of the Experimental Sites during 2022 and 2023 rainy season.

Location	Kura		Tokarawa	
	2022	2023	2022	2023
Physical Composition				
Clay	28.39	26.40	25.60	23.34
Silt	21.40	19.28	18.30	19.83
Sand	50.21	54.32	56.10	56.65
Textural class	Sandy-Loam	Sandy	Sandy-Loam	Sandy-Loam
Chemical Composition				
pH in H ₂ O	6.1	6.4	6.3	5.9
pH in CaCl ₂	5.16	5.59	6.5	6.20
Organic carbon (g kg ⁻¹)	0.65	0.68	1.09	1.12
Total Nitrogen (g kg ⁻¹)	0.35	0.39	0.26	0.21
Available P (mg/kg)	5.01	5.43	5.62	5.82
Exchangeable Bases (Cmolkg⁻¹)				
Ca ⁺⁺	1.81	1.64	4.19	2.23
Mg ⁺⁺	1.20	0.42	0.67	1.12
K ⁺	0.26	0.19	0.23	0.21
Na ⁺	0.19	0.17	0.22	0.28
CEC (cmolkg ⁻¹)	4.53	2.82	7.07	3.68

Table 2: Effect of Micronutrients Coated Urea and Sulphur on Plant Height (cm²) at Kura and Tokarawa during 2022 and 2023 wet season

Treatment	Kura						Tokarawa					
	2022			2023			2022			2023		
	4WAS	8WAS	12WAS	4WAS	8WAS	12WAS	4WAS	8WAS	12WAS	4WAS	8WAS	12WAS
Control (kg)	41.27 ^c	56.43 ^g	64.68 ^e	40.13 ^e	57.13 ^f	63.80 ^c	32.83 ^e	57.00 ^b	72.23 ^e	37.27 ^e	65.85 ^b	73.67 ^b
2.5BCTU	48.00 ^{ab}	124.13 ^{bcd}	223.58 ^{abcd}	46.51 ^{bc}	127.27 ^{bc}	223.63 ^a	59.47 ^{ab}	121.00 ^a	169.10 ^{cd}	55.80 ^{abc}	117.67 ^a	150.30 ^a
1.25BCTU	47.00 ^b	124.00 ^{bcd}	217.25 ^{abcd}	47.50 ^{bc}	120.97 ^{cd}	223.52 ^a	57.13 ^{abc}	124.00 ^a	172.87 ^{bcd}	57.63 ^{abc}	131.73 ^a	166.10 ^a
2.5Zn CTU	49.73 ^{ab}	123.33 ^{cd}	226.07 ^{abc}	53.90 ^a	120.67 ^{cd}	214.98 ^{ab}	51.80 ^{abc}	130.00 ^a	170.80 ^{cd}	52.20 ^{cd}	128.00 ^a	150.63 ^a
1.25Zn CTU	47.07 ^b	126.30 ^{bcd}	202.07 ^d	47.93 ^{bc}	125.87 ^{bc}	208.40 ^{ab}	51.20 ^{abc}	133.00 ^a	166.44 ^d	53.40 ^{abcd}	124.60 ^a	156.37 ^a
20kg S	40.40 ^c	66.30 ^f	77.85 ^e	41.00 ^{de}	61.60 ^f	79.72 ^c	40.20 ^d	61.17 ^b	76.73 ^e	42.70 ^d	66.83 ^b	80.93 ^b
40kg S	40.97 ^c	70.53 ^f	82.32 ^e	39.84 ^e	56.60 ^f	73.73 ^c	42.43 ^d	57.93 ^b	79.80 ^e	41.50 ^d	63.27 ^b	75.20 ^b
2.5BCTU + 20S	47.40 ^b	134.73 ^{ab}	224.72 ^{abc}	49.80 ^{ab}	132.80 ^b	224.05 ^a	54.93 ^{ac}	146.93 ^a	199.53 ^{abcd}	58.17 ^{ab}	135.93 ^a	180.90 ^a
2.5BCTU + 40S	49.00 ^{ab}	141.03 ^a	232.03 ^{ab}	47.03 ^{bc}	140.40 ^a	221.62 ^a	51.43 ^{abc}	147.07 ^a	213.53 ^{ab}	59.57 ^{ab}	137.53 ^a	182.60 ^a
1.25BCTU + 20S	47.97 ^{ab}	128.07 ^{bcd}	207.65 ^{cd}	46.50 ^{bc}	126.30 ^{bc}	200.10 ^{ab}	61.87 ^a	145.40 ^a	210.27 ^{abc}	64.00 ^{ab}	131.67 ^a	186.43 ^a
1.25BCTU + 40S	49.40 ^{ab}	119.60 ^{cde}	209.47 ^{bcd}	50.32 ^{ab}	119.40 ^{cd}	210.60 ^{ab}	54.93 ^{abc}	146.67 ^a	233.08 ^a	60.97 ^{ab}	135.67 ^a	196.60 ^a
2.5Zn CTU + 20S	49.47 ^{ab}	124.67 ^{bcd}	225.28 ^{abc}	44.50 ^{cd}	122.53 ^{cd}	182.37 ^b	51.47 ^{abc}	143.93 ^a	230.27 ^a	55.63 ^{abc}	125.83 ^a	171.33 ^a
2.5Zn CTU + 40S	51.17 ^a	128.80 ^{bc}	238.95 ^a	47.25 ^{bc}	127.53 ^{bc}	214.85 ^{ab}	54.07 ^{abc}	133.47 ^a	238.50 ^a	66.80 ^a	128.97 ^a	192.67 ^a
1.25ZnCTU + 20S	48.40 ^{ab}	110.20 ^e	210.42 ^{bcd}	47.97 ^{bc}	105.13 ^e	206.48 ^{ab}	57.83 ^{abc}	128.27 ^a	201.00 ^{abcd}	57.07 ^{abc}	118.27 ^a	182.13 ^a
1.25ZnCTU+ 40S	47.90 ^{ab}	117.03 ^{de}	216.75 ^{abcd}	46.08 ^{bc}	114.87 ^d	211.82 ^{ab}	51.27 ^{abc}	128.93 ^a	203.13 ^{abcd}	57.87 ^{abc}	126.67 ^a	158.97 ^a
SE±	1.04	3.37	6.75	1.37	2.45	10.71	4.55	8.79	12.69	3.99	6.63	14.51
Mean	47.01	113.01	190.61	46.42	110.60	183.98	52.39	120.98	175.82	55.10	115.89	153.46
P value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	0.002	<.0001	<.0001

Means followed by the same letter(s) within a treatment group are not statistically different at 5% level of probability using DMRT.

NS = Not Significant * = Significant at 5% probability level ** =Significant at 1% probability level WAS=Weeks After Sowing

Key- B= Boron, Zn=Zinc, S=Sulphur CTU=coated urea

Table 3: Effect of micronutrients coated urea and Sulphur on the performance of Sorghum Leaf Area Index at Kura and Tokarawa during 2022 and 2023 Wet season

Treatment	Kura						Tokarawa					
	2022			2023			2022			2023		
	4WAS	8WAS	12WAS	4WAS	8WAS	12WAS	4WAS	8WAS	12WAS	4WAS	8WAS	12WAS
Control (kg)	0.03 ^e	0.03 ^d	0.03 ^g	0.03 ^c	0.03 ^c	0.03 ^c	0.02 ^c	0.03 ^d	0.03 ^c	0.02 ^d	0.03 ^b	0.04 ^b
2.5BCTU	0.04 ^{bc}	0.04 ^{bc}	0.05 ^{abc}	0.04 ^{ab}	0.05 ^{ab}	0.05 ^{ab}	0.04 ^a	0.04 ^{bc}	0.05 ^b	0.03 ^{abc}	0.06 ^a	0.08 ^a
1.25BCTU	0.03 ^d	0.04 ^{bc}	0.05 ^e	0.04 ^{ab}	0.04 ^b	0.05 ^b	0.04 ^a	0.05 ^b	0.05 ^b	0.03 ^{abc}	0.07 ^a	0.09 ^a
2.5Zn CTU	0.04 ^c	0.04 ^{bc}	0.05 ^{bcd}	0.04 ^{ab}	0.05 ^{ab}	0.05 ^{ab}	0.04 ^a	0.05 ^{ab}	0.05 ^b	0.03 ^{bcd}	0.07 ^a	0.08 ^a
1.25Zn CTU	0.04 ^{cd}	0.04 ^{bc}	0.05 ^{cd}	0.03 ^b	0.04 ^b	0.05 ^b	0.03 ^{ab}	0.04 ^b	0.05 ^b	0.03 ^{abcd}	0.06 ^a	0.08 ^a
20kg S	0.02 ^{ef}	0.03 ^d	0.04 ^f	0.03 ^c	0.03 ^c	0.04 ^c	0.02 ^c	0.03 ^c	0.04 ^c	0.02 ^{cd}	0.03 ^b	0.04 ^b
40kg S	0.02 ^f	0.03 ^d	0.04 ^f	0.02 ^c	0.03 ^c	0.04 ^c	0.02 ^c	0.03 ^d	0.04 ^c	0.02 ^d	0.03 ^b	0.04 ^b
2.5BCTU + 20S	0.04 ^a	0.05 ^a	0.06 ^a	0.04 ^a	0.05 ^a	0.06 ^a	0.03 ^b	0.05 ^b	0.06 ^b	0.03 ^{ab}	0.07 ^a	0.09 ^a
2.5BCTU + 40S	0.04 ^{ab}	0.05 ^a	0.06 ^a	0.04 ^{ab}	0.05 ^a	0.06 ^a	0.04 ^a	0.06 ^a	0.07 ^a	0.03 ^a	0.07 ^a	0.10 ^a
1.25BCTU +20S	0.04 ^{bc}	0.04 ^{bc}	0.05 ^{cd}	0.04 ^{ab}	0.04 ^b	0.05 ^b	0.03 ^{ab}	0.05 ^{ab}	0.05 ^b	0.03 ^{ab}	0.07 ^a	0.10 ^a
1.25BCTU +40S	0.04 ^c	0.05 ^{abc}	0.05 ^{cd}	0.04 ^{ab}	0.04 ^{ab}	0.05 ^b	0.03 ^{ab}	0.05 ^b	0.05 ^b	0.03 ^{ab}	0.07 ^a	0.09 ^a
2.5Zn CTU +20S	0.04 ^c	0.05 ^{ab}	0.05 ^{cd}	0.04 ^a	0.05 ^{ab}	0.05 ^{ab}	0.04 ^a	0.05 ^{ab}	0.06 ^b	0.03 ^{abc}	0.06 ^a	0.09 ^a
2.5Zn CTU +40S	0.04 ^{bc}	0.05 ^{abc}	0.05 ^{ab}	0.04 ^a	0.05 ^{ab}	0.05 ^{ab}	0.04 ^{ab}	0.05 ^{ab}	0.06 ^b	0.03 ^{ab}	0.07 ^a	0.10 ^a
1.25ZnCTU +20S	0.04 ^c	0.04 ^c	0.05 ^{de}	0.04 ^{ab}	0.04 ^b	0.05 ^{ab}	0.03 ^{ab}	0.05 ^b	0.05 ^b	0.03 ^{abc}	0.06 ^a	0.09 ^a
1.25ZnCTU+ 40S	0.04 ^{cd}	0.04 ^{bc}	0.05 ^{cd}	0.03 ^b	0.04 ^{ab}	0.05 ^{ab}	0.04 ^{ab}	0.05 ^b	0.05 ^b	0.03 ^{abc}	0.07 ^a	0.08 ^a
SE±	0.87	1.32	1.13	1.17	1.43	0.003	0.002	0.003	0.004	0.003	0.003	0.006
Mean	0.03	0.04	0.05	0.03	0.04	0.05	0.03	0.04	0.05	0.03	0.06	0.08
P value	<.000	<.0001	<.0001	<.0001	<.0001	<.0001	<0.001	<0.001	<0.001	0.002	<0.001	<0.001

Means followed by the same letter(s) within a treatment group are not statistically different at 5% level of probability using DMRT.

NS = Not Significant *= Significant at 5% probability level** =Significant at 1% probability level,WAS=Weeks After Sowing

Key- B= Boron, Zn=Zinc, S=Sulphur CTU=coated Urea

Table 4: Effect of micronutrients coated urea and Sulphur on Sorghum Net assimilation rate at Kura during the 2022 and 2023 wet season.

Treatment	Kura				Tokarawa			
	2022		2023		2022		2023	
	4WAS	8WAS	4WAS	8WAS	4WAS	8WAS	4WAS	8WAS
Control (kg)	0.23 ^e	0.59 ^d	0.27 ^f	0.58 ^c	0.20 ^d	0.41 ^e	0.23 ^c	0.31 ^c
2.5B CTU	0.36 ^{bc}	3.20 ^a	0.35 ^{bcdef}	3.09 ^a	0.32 ^{abc}	0.54 ^{ab}	0.53 ^{bc}	0.52 ^{abc}
1.25BCTU	0.32 ^{cde}	2.84 ^{ab}	0.33 ^{cdef}	2.77 ^a	0.26 ^{bcd}	0.46 ^{bc}	0.54 ^b	0.49 ^{abc}
2.5Zn CTU	0.37 ^{abc}	2.98 ^{ab}	0.39 ^{bc}	2.86 ^a	0.32 ^{abc}	0.44 ^{ab}	0.56 ^{ab}	0.48 ^{bc}
1.25Zn CTU	0.27 ^{de}	2.59 ^b	0.38 ^{bcde}	1.99 ^b	0.33 ^{cd}	0.52 ^{ab}	0.54 ^{ab}	0.49 ^{abc}
20kg S	0.25 ^e	1.00 ^{cd}	0.29 ^{ef}	1.08 ^c	0.23 ^d	0.39 ^e	0.20 ^c	0.31 ^c
40kg S	0.26 ^e	1.22 ^c	0.28 ^{ef}	1.01 ^c	0.21 ^d	0.41 ^{cd}	0.27 ^c	0.35 ^c
2.5B CTU + 20S	0.37 ^{abc}	3.16 ^a	0.39 ^{bcd}	3.21 ^a	0.42 ^a	0.44 ^{ab}	0.56 ^{ab}	0.53 ^{ab}
2.5B CTU + 40S	0.46 ^a	3.20 ^a	0.49 ^a	3.27 ^a	0.43 ^a	0.59 ^a	0.57 ^a	0.54 ^a
1.25B CTU +20S	0.35 ^{bcd}	2.97 ^{ab}	0.39 ^{bc}	3.15 ^a	0.34 ^{abc}	0.56 ^{ab}	0.56 ^{ab}	0.51 ^{abc}
1.25B CTU +40S	0.42 ^{ab}	3.29 ^a	0.41 ^{abc}	3.08 ^a	0.38 ^{ab}	0.54 ^{ab}	0.56 ^{ab}	0.49 ^{abc}
2.5Zn CTU +20S	0.44 ^{ab}	3.29 ^a	0.45 ^{ab}	3.25 ^a	0.32 ^{abc}	0.54 ^{ab}	0.55 ^{ab}	0.53 ^{abc}
2.5Zn CTU +40S	0.45 ^{ab}	3.28 ^a	0.43 ^{abc}	3.02 ^a	0.39 ^a	0.56 ^{ab}	0.56 ^{ab}	0.51 ^{abc}
1.25ZnCTU +20S	0.38 ^{abc}	2.96 ^{ab}	0.37 ^{bcdef}	2.88 ^a	0.38 ^{ab}	0.44 ^{ab}	0.55 ^{ab}	0.51 ^{abc}
1.25ZnCTU+ 40S	0.41 ^{abc}	3.27 ^a	0.39 ^{bc}	3.22 ^a	0.38 ^a	0.51 ^{bc}	0.56 ^{ab}	0.49 ^{abc}
SE±	0.03	0.15	0.03	0.27	0.03	0.02	0.02	0.01
Mean	0.36	2.66	0.38	2.57	0.34	0.48	0.55	0.51
P value	0.004	<.0001	<0.001	<.0001	0.004	<.0001	0.06	0.02

Means followed by the same letter(s) within a treatment group are not statistically different at 5% level of probability using DMRT.

NS =Not Significant* = Significant at 5% probability level** =Significant at 1% probability level, WAS=Weeks After Sowing

Key- B= Boron, Zn=Zinc, S=Sulphur CTU=coated urea

Table 5: Effect of micro coated urea and Sulphur on 100 Grain weight of Sorghum at Kura and Tokarawa during the 2022 and 2023 wet season

Treatment	KURA		Tokarawa	
	2022	2023	2022	2023
	100 Grain weight (g)	100 Grain weight (g)	100 Grain weight (g)	100 Grain weight(g)
Control (kg)	3.33 ^c	4.00 ^b	4.00 ^d	3.33 ^c
2.5BCTU	5.33 ^{ab}	5.33 ^a	5.00 ^{abcd}	5.67 ^{ab}
1.25BCTU	4.67 ^{abc}	5.33 ^a	6.00 ^b	5.33 ^{ab}
2.5Zn CTU	5.67 ^a	6.00 ^a	5.33 ^{abc}	5.67 ^{ab}
1.25Zn CTU	5.00 ^{ab}	5.67 ^a	5.67 ^{ab}	5.67 ^{ab}
20kg S	4.33 ^{abc}	4.00 ^b	4.67 ^{bcd}	4.00 ^c
40kg S	4.00 ^{bc}	4.33 ^b	4.33 ^{cd}	4.00 ^c
2.5BCTU + 20S	4.67 ^{abc}	5.67 ^a	5.67 ^{ab}	5.67 ^{ab}
2.5BCTU + 40S	5.67 ^a	6.00 ^a	6.33 ^a	6.00 ^a
1.25BCTU +20S	5.67 ^a	5.67 ^a	5.00 ^{abcd}	5.00 ^b
1.25BCTU +40S	4.67 ^{abc}	5.67 ^a	5.33 ^{abc}	5.00 ^b
2.5Zn CTU +20S	5.00 ^{ab}	6.00 ^a	5.00 ^{abcd}	5.67 ^{ab}
2.5Zn CTU +40S	5.33 ^{ab}	5.33 ^a	5.33 ^{abc}	6.00 ^a
1.25ZnCTU +20S	5.33 ^{ab}	5.33 ^a	4.67 ^{bcd}	5.00 ^b
1.25ZnCTU+ 40S	5.00 ^{ab}	5.33 ^a	5.33 ^{abc}	5.00 ^b
SE±	0.42	0.28	0.38	0.27
Mean	4.91	5.31	5.18	5.13
P value	0.03	<.0001	0.04	<.0001

Means followed by the same letter(s) within a treatment group are not statistically different at 5% level of probability using DMRT. NS = Not Significant * = Significant at 5% probability level ** =Significant at 1% probability level, WAS=Weeks After Sowing Key- B= Boron, Zn=Zinc, S=Sulphur CTU=coated Urea

Table 6:Effect of micro coated urea and Sulphur on Sorghum grain weight/plot and Grain weight/hectare at Kura and Tokarawa 2022 and 2023 wet season

Treatment	Kura				Tokarawa			
	2022		2023		2022		2023	
	Grain weight per plot(g)	Grain weight per hectare(kg)	Grain weight per plot(g)	Grain weight per hectare(kg)	Grain weight per plot(g)	Grain weight per hectare(kg)	Grain weight per plot(g)	Grain weight per hectare(kg)
Control (kg)	272.40 ^f	302.7 ^f	297.76 ^g	330.84 ^g	261.92 ⁱ	291.02 ⁱ	279.80 ^k	310.89 ^k
2.5BCTU	826.44 ^b	918.7 ^b	875.32 ^b	972.58 ^b	858.56 ^c	953.96 ^c	873.76 ^c	970.84 ^c
1.25BCTU	790.16 ^{bc}	877.6 ^{bc}	752.68 ^d	836.31 ^d	760.36 ^e	844.84 ^e	792.48 ^{ef}	880.53 ^{ef}
2.5Zn CTU	843.96 ^b	937.3 ^b	847.80 ^{bc}	942.00 ^{bc}	852.12 ^c	946.80 ^c	813.72 ^{de}	904.13 ^{de}
1.25Zn CTU	666.08 ^d	740.9 ^d	668.00 ^e	742.22 ^e	755.92 ^e	839.91 ^e	698.28 ^h	775.87 ^h
20kg S	449.88 ^e	499.7 ^e	429.48 ^f	477.20 ^f	382.60 ^h	425.11 ^h	428.64 ^j	476.27 ^j
40kg S	456.16 ^e	508.4 ^e	427.64 ^f	475.16 ^f	482.40 ^g	536.00 ^g	409.52 ^j	455.02 ^j
2.5BCTU + 20S	702.20 ^{cd}	780.2 ^{cd}	846.80 ^{bc}	940.89 ^{bc}	793.68 ^{de}	881.87 ^{de}	806.16 ^e	895.73 ^e
2.5BCTU + 40S	1058.04 ^a	1156.0 ^a	1091.48 ^a	1212.76 ^a	1118.48 ^a	1242.76 ^a	1097.64 ^a	1219.60 ^a
1.25BCTU +20S	635.68 ^d	706.1 ^d	671.12 ^e	745.69 ^e	655.32 ^f	728.13 ^f	644.24 ⁱ	715.82 ⁱ
1.25BCTU +40S	788.92 ^{bc}	876.8 ^{bc}	775.64 ^d	861.82 ^d	797.68 ^{de}	886.31 ^{de}	737.12 ^{gh}	819.02 ^{hg}
2.5Zn CTU +20S	864.24 ^b	960.7 ^b	825.76 ^c	917.51 ^c	812.92 ^d	903.24 ^d	805.08 ^e	894.53 ^e
2.5Zn CTU +40S	977.68 ^a	1086.1 ^a	1061.96 ^a	1179.96 ^a	908.92 ^b	1009.91 ^b	971.04 ^b	1078.93 ^b
1.25ZnCTU +20S	686.84 ^d	763.6 ^d	742.40 ^d	824.89 ^d	794.84 ^{de}	883.16 ^{de}	851.92 ^{cd}	946.58 ^{cd}
1.25ZnCTU+ 40S	859.96 ^b	955.1 ^b	822.60 ^c	914.00 ^c	855.56 ^c	950.62 ^c	752.48 ^{fg}	836.09 ^{fg}
SE±	12.56	14.79	12.62	14.03	13.25	14.72	14.81	16.45
Mean	725.24	804.66	742.43	824.92	739.42	821.58	730.79	811.99
P value	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001

Means followed by the same letter(s) within a treatment group are not statistically different at 5% level of probability using DMRT.

NS = Not Significant * = Significant at 5% probability level ** =Significant at 1% probability level, WAS=Weeks After Sowing

Key- B= Boron, Zn=Zinc, S=Sulphur CTU=coated urea

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