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RESEARCH ARTICLE

Yield variability of soybean [*Glycine max* (L.) Merrill] as affected by foliar applied kaolin under irrigation in Sudan savanna of Nigeria

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ABSTRACT

A field trial was conducted during the hot, dry season in 2020 to assess the effect of foliar-applied antitranspirant (Kaolin) on yield and yield components of irrigated soybean [*Glycine max* (L.) Merrill]. Treatments consisted of two varieties of soybean (TGX1835-10E and TGX1955-4F), three growth stages for the application of kaolin (node initiation, flower initiation, and pod initiation), and application rates (0%, 3%, 6%, and 9% w/v). The factors were factorially combined and laid out in a split-split-plot design and replicated three times. The result obtained after comparison between two varieties of soybean, three growth stages of foliar applied kaolin, and four kaolin rates indicated that variety, application at growth stage, and kaolin rates indicated higher significance, significance and non-significance effects on measured; number of pods plant^{-1}, seed pod^{-1}, hundred seed weight (g), grain and fodder yield (kg ha^{-1}) taken at harvest. The average yield of 2.3 t ha^{-1} was recorded in TGX1835-10E and 2.5 t ha-1 in TGX1955-4F. Kaolin applied at flower and pod initiation recorded a higher grain yield at BUK, and at Kadawa application at pod initiation recorded a higher grain yield. Kaolin rates applied at 3 and 6% averagely indicated grain yield of 2.8 t ha^{-1} and 2.7 t ha^{-1}, respectively. Applying 3% kaolin rate is recommended for soybean production in area with low heat load (low temperature) on leaf surfaces within the growing cycle of the crop and 6% rate in area with higher heat load (higher temperature) on leaf surfaces.

Keywords: Hot dry season, variety, growth stage, kaolin rate, yield and yield components.

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is in the family of Fabaceae and an important crop across most states in Nigeria as it is a major source of protein, carbohydrate, fat, vitamins, minerals, calcium, folic acid, and iron (Ruth et al., 2017; Shang & Chaplot, 2017; Madu et al., 2023). Soybean uses in human consumption, milk production, oil processing, medicine, industrial use, poultry, and livestock feeds increased the crop's demand for a rapidly growing population. In the research area, crop production is seldom during the wet season, which is associated with the incidences of pests, diseases, and climatic variables that affect crop performances and final yield. Although higher grain yield could be achieved under irrigation to address the volume of demand, such could be constrained by climatic variables, particularly high transpiration rate, which is a stress that can adversely affect the yield and yield component of the crop. Although plants, through various mechanisms, increase resistance to high transpiration rates with that aside artificial ways are another development in agriculture. Reducing crop luxury transpiration is essential in improving water productivity (Kang et al., 2017).

Antitranspirant (kaolin) spray on plant leaves was found to decrease leaf temperature in crops by increasing leaf reflectance and reducing transpiration rate more than photosynthesis in many plant species grown at high solar radiation levels (Nakano & Uehara, 1996), thereby affecting yield and yield component. Sequel to stress due high transpiration rate in soybean grown during the hot, dry season in the Sudan savanna, which can reduce yield, there is a need to find ways to reduce water losses through high transpiration in crops, which could lead to higher yield. Using kaolin as an antitranspirant was an effective method and most appropriate when better variety at the right growth stage and correct rates are applied. Therefore, the need "to evaluate the effect of foliar applied kaolin on yield and yield components of soybean under irrigation."

MATERIALS AND METHODS

The trial was conducted during the hot, dry season of 2020 in the Sudan savanna of Nigeria to evaluate the effect of foliar-applied kaolin on the growth, yield, and yield components of irrigated soybean. It was conducted in the Teaching and Research Farm of the Faculty of Agriculture Bayero University, Kano (11̊ 97' 98.6" N, 8̊ 42' 03.7" E) 475 m elevation and the Irrigation Research Station, Kadawa Kano under the Institute for Agricultural Research Ahmadu Bello University Zaria, Kaduna (11̊ 38'.40.3" N 8̊ 25' 53.9" E) 498 m elevation. The treatments consisted of two varieties of soybean, three growth stages of foliar-applied kaolin (node, flower, and pod initiation), and four rates of kaolin. The factors were factorially combined and laid out in a split-split-plot design and replicated three times. Varieties were allocated to main plots, growth stages of foliar-applied kaolin in subplots, and kaolin rates in sub-subplots. TGX1835-10E and TGX1955-4F are known for resistance to pests and diseases, high yielding, and suitable for the Sudan savannah zone (Dugje *et al.,* 2009). The seeds were inoculated with (*Brady rhizobium Japonicum*) and seeds treatment with fungicides (Captan, Apron Plus at the rate of 1 sachet/8 kg of seeds before planting for protection against soil-borne fungal diseases.

The field of each experimental site marked out in a total size of 1150.5m^2. It was divided into three replications with an alley of 2 m. Replications were transformed into main, sub, and sub-sub plots of 3 m by 5 m with an alley of 0.75 m between each. The main plot, sub-plot, and sub-sub plot consisted of 4 ridges of 5m by 0.75 m (15 m2) and net plot sizes (two inner rows) of 4.5 m^2. Sowing was observed manually on four ridges side, 6 seeds per hole, and was thinned to 4 plants at 3 WAS. Spacing between ridges was 0.75 m^2 and 10 cm between stands with a depth of about 3 to 4 cm. Supplying was donned ten days after sowing.

Through surface flooding, irrigation water was conveyed to the research plots basin. The interval of four days between irrigation was maintained in BUK and 7day in Kadawa due to variation in the water table and withdrew at pods maturity. Powdered, water-soluble kaolin was sieved and diluted in water into different rates (0%, 3%, 6%, and 9% w/v) and applied on leaves surfaces. The rates were obtained through the following;

1g →1ml =100%

1g→99ml = 1%

For 99ml to liter → (÷ 1000/99 = 0.099ml)

Therefore 1% in 15liter of water →X x 15/0.099 = 1g x 15litre/0.099

X = 1x 15/0.099 =151.5g is 1% in 15liter of water

For 3% 151.5g x 3 =454.5g

For 6% 151.5 x 6= 909g

For 9% 151.5g x 9=1363.5g

According to treatment allocation and rates, a fine mist of kaolin solutions was sprayed on top and bottom of leaves surfaces until run off with hand operated (pressure) sprayer. Treatments were in the morning hours and repeated three times at five-day intervals as kaolin should be applied before high temperatures and must be reapplied to protect new growth (Sharma et al., 2015).

Harvesting

At maturity, the pod is straw-colored; outer rows were harvested first by cutting the plant from the ground level, followed by sample plant and net plots for data collection.

Threshing

Properly dried samples and net plot yield were manually threshed by putting them inside sacks and beating them with a stick. Winnowing to remove the seeds from the debris followed, and total fodder was collected and weighed.

Number of Pods Plant^{-1}

At harvesting, pods from five sampled plants were removed, counted, and the average was recorded as pods plant^{-1}.

100 Grain Weight (g)

One hundred grains from sampled plants were weighed and recorded.

Grain Yield (kg ha^{-1})

Termex 16 moisture regulator (15% MC) was used to reduce moisture content in the grain yield of tagged plants measured in gram and extrapolated in kilogram per hectare using the formula below.

$$GY = \frac{\text{Grain Yield } (\text{kgha}^{-1}) \text{ x } 10{,}000(m^2)}{Plot\ Area\ (m^2)}$$

Fodder Yield (kg ha^{-1})

At the final harvest, tagged plants (above-ground biomass) from net plots were separated into pods and shoots. Total above-ground biomass was then cut into small pieces and packed in envelopes, and oven-dried at 70 °C; weight was recorded and extrapolated on a per-hectare basis.

$$FD = \frac{\text{Fodder Yield } (\text{kgha}^{-1}) \text{ x } 10{,}000(m^2)}{Plot\ Area\ (m^2)}$$

Data Analysis

The data collected were subjected to analysis of variance (ANOVA) using Statistix-10, where significant means of treatments were separated using Tukey HSD at a 5% probability level.

RESULTS

Number of Pods Plant^{-1}

The effect of variety, application at the growth stage, and kaolin rates on a number of pods plant-1 at BUK and Kadawa during the 2020 dry season is presented in **Table 1**. The study shows that variety had no significant effect on the number of pods plant^{-1} produced across locations. The effect of kaolin application at the growth stage at BUK produced significantly ($P \leq 0.01$) the highest number of pods plant^{-1} with kaolin applied at flower and pod initiation and lower at node initiation. At Kadawa, application at flower initiation was higher, followed by a pod initiation, and the least number was recorded in the application at node initiation. The effect of kaolin rate at Kadawa produced significantly ($P \leq 0.01$) a higher number of pods plant^{-1} in the application of 3 and 6% kaolin and at par indicated lower in the application of 9% and the control. Significant interactions were recorded across locations.

Interaction

At BUK, the interaction of variety and application at the growth stage recorded significantly ($P \leq 0.01$) the highest number of pods plant-1 due to application at flower initiation in TGX1955-4F and had statistical similarity with the plant treated at pod initiation of TGX1955-4F (**Table 2**). Although the lower number of the pod was in the application at flower and pod initiation in TGX1835-10E, the statistical similarity was recorded with the application at pod initiation of TGX1955-4F, and the lowest number was in the application at node initiation across varieties.

The interaction of the growth stage of foliar-applied kaolin and its rates was significant ($P \leq 0.01$) at BUK. The highest numbers of pods plant^{-1} were recorded with an application of 3% at flower and pod initiation, followed by a number of pods plant^{-1} at 6% with the application at flower initiation. Kaolin application at node initiation had the lowest number of pod plant^{-1} at the control and 9% rate. In the interaction of application at the growth stage and kaolin rate at Kadawa indicated the highest number of pods plant^{-1} with the application of 6% kaolin at flower initiation and the lowest number of pods plant^{-1} at the control in the application at node initiation (**Table 3**).

Hundred Seed Weight (g)

The effect of variety, the growth stage of foliar applied kaolin, and its kaolin rate on hundred seed weight of soybean at BUK and Kadawa during the 2020 dry season are presented in (**Table 1**). The study indicated that variety had no significant effect on hundred seed weight across locations. The effect of kaolin application at the growth stage at Kadawa produced significantly (P≤ 0.01) the highest hundred seed weight with the application at pod initiation and lower with the application at node and flower initiation.

The effect of kaolin rate at BUK was recorded significantly (P≤ 0.01) highest hundred seed weight with the application of 3% and statistically shows similarity in hundred seed weight with the application of 6% kaolin. However, the lower hundred seed weight obtained at the control indicated similarity with applying 9% kaolin, which was the lowest number of pods plant^{-1}. At Kadawa, the application of 3 and 6% kaolin recorded significantly (P≤ 0.01) the highest hundred seed weight and lower with the application of 9% kaolin and the control. A significant interaction was recorded during the trial.

Interaction

Interaction between application at the growth stage and kaolin rates in (**Table 4**) at Kadawa shows that significantly (P≤ 0.05) highest hundred seed weight was recorded with the application of 6% kaolin at pod initiation. It was statistically similar in hundred seed weight with the application of 3% at flower and pod initiation, 6% at flower initiation, and 9% at pod initiation. The lowest hundred seed weight was recorded across the growth stage at control.

Table 1. Number of Pod Plant-^{1} and Hundred Seeds Weight (g) of Soybean as Affected by Variety, Growth Stage of Foliar Applied Kaolin and its Rate at BUK and Kadawa during the 2020 Dry Season.

Treatment	Number of Pod plant^{-1}		Hundred Seeds Weight (g)	
	BUK	Kadawa	BUK	Kadawa
Variety (V)				
TGX1835-10E	84.80	119.53	14.32	15.09
TGX1955-4F	92.75	111.31	14.44	15.01
P-Value	0.119	0.172	0.796	0.712
SE (±)	3.028	3.928	0.414	0.209
Growth Stage (GS)				
Node Initiation	73.44^{b}	94.81^{c}	13.85	14.59^{b}
Flower Initiation	97.50^{a}	133.49^{a}	14.46	14.86^{b}
Pod Initiation	95.41^{a}	117.95^{b}	14.85	16.10^{a}
P-Value	0.001	0.003	0.084	0.005
SE (±)	2.367	5.401	0.385	0.247
Kaolin Rate (R)				
0%	77.59^{b}	104.38^{b}	14.08^{bc}	15.10^{b}
3%	101.64^{a}	126.28^{a}	14.61^{ab}	15.39^{a}
6%	93.98^{a}	128.12^{a}	14.84^{a}	15.53^{a}
9%	81.91^{b}	102.89^{b}	14.00^{c}	14.77^{b}
P-Value	0.001	0.001	0.007	0.001
SE (±)	3.481	4.110	0.265	0.220
Interaction				
V* GS	0.013	0.2988	0.246	0.630
V*R	0.916	0.8782	0.460	0.204
GS *R	0.018	0.0344	0.230	0.038
V* GS *R	0.476	0.0635	0.069	0.597

Means along the same column with unlike letter (s) are different at 5% level of probability.

Table 2. Interaction between Variety and Growth Stage of Foliar Applied Kaolin on Number of Pods Plant^{-1} of Soybean at BUK Dry Season.

BUK	Growth Stage		
	NODIN	FLOIN	PODIN
Variety			
TGX1835-10E	74.13^{c}	88.78^{b}	91.48^{b}
TGX1955-4F	72.74^{c}	106.22^{a}	99.33^{ab}

SE (±)	3.347	-	-

Means with unlike letter (s) are different at 5% level of probability. NODIN= node initiation, FLOIN = flower initiation and PODIN= pod initiation.

Table 3. Interactions between Growth Stages of Foliar Applied Kaolin and Kaolin Rate on Number of Pods plant^{-1} of Soybean at BUK and Kadaw Dry Season.

	BUK				Kadawa			
GS/Rate	0%	3%	6%	9%	0%	3%	6%	9%
NODIN	63.60^{f}	80.00^{c-f}	77.13^{def}	73.02^{ef}	86.52^{h}	101.67^{fg}	99.52^{fgh}	91.55^{gh}
FLOIN	94.07^{a-d}	110.48^{a}	99.30^{abc}	86.15^{b-d}	119.47^{cde}	141.57^{b}	156.62^{a}	116.30^{def}
PODIN	75.12^{def}	114.43^{a}	105.52^{ab}	86.57^{c-d}	107.15^{efg}	135.62^{bc}	128.23^{bcd}	100.81^{fgh}
SE (±)	6.030				7.119			

Means with unlike letter (s) are different at 5% level of probability. GS= growth stage, NODIN= node initiation, FLOIN = flower initiation and PODIN= pod initiation.

Table 4. Interaction between Growth Stage of Foliar Applied Kaolin and Kaolin Rate on Hundred Seeds Weight (g) of Soybean at Kadawa Dry Season.

Kadawa	Rate			
	0%	3%	6%	9%
Growth Stage				
NODIN	14.67^{c}	14.55^{c}	14.87^{bc}	14.28^{c}
FLOIN	14.25^{c}	15.33^{abc}	15.22^{abc}	14.65^{c}
PODIN	14.60^{c}	16.28^{ab}	16.52^{a}	15.38^{abc}
SE (±)		0.380	0.321	0.181

Means with unlike letter (s) are different at 5% level of probability. NODIN= node initiation, FLOIN = flower initiation, PODIN= pod initiation.

Grain Yield (kg ha^{-1})

Grain yield as affected by variety, growth stage for application of kaolin, and its kaolin rate at BUK and Kadawa during the 2020 dry season is presented in Table 5. The result of the study indicated that grain yield was not significantly affected by variety across the locations. The effect of application at the growth stage recorded significantly (P≤ 0.01) higher grain yield in the application at flower and pod initiation and lower at node initiation across the locations. However, the effect of kaolin rate on grain yield at BUK produced significantly (P≤ 0.01) the highest grain yield with the application of 6% kaolin. It indicated statistical similarity in grain yield with the application of 3% kaolin and was followed by the application of 9 % kaolin. Lower grain yield was at the control and showed statistical similarity in applying 9% kaolin. At Kadawa effect of the kaolin rate indicated significantly (P≤ 0.01) the highest grain yield with the application of 3 and 6% kaolin and lower at the control and 9%. No significant interaction was recorded from the seasons.

Fodder Yield (kg ha^{-1})

The effect of variety, the growth stage of foliar applied kaolin and its kaolin rate, and there on fodder yield of soybean at BUK and Kadawa during the 2020 dry season is presented in (Table 5). TGX1955-4F recorded significantly (P≤ 0.05) highest fodder yield than TGX1835-10E at BUK. The effect of kaolin application at the growth stage recorded significantly (P≤ 0.05) highest fodder yield with the application at flower initiation and shows statistical similarity with fodder yield obtained in the application at node initiation. Although lower fodder yield was recorded with the application at pod initiation, statistically had similar fodder yield with the application at pod initiation.

The effect of kaolin rates on fodder yield at BUK (**Table 5**) produced significantly (P≤ 0.01) highest fodder yield was obtained with the application of 6% kaolin and indicated statistical similarity in the application of 3% kaolin. Lower fodder yield with the application of 9% kaolin was statistically similar to the control and 3% kaolin. The lowest fodder yield obtained at the control was statistically similar in fodder yield recorded with 9% kaolin. However, at Kadawa, the application of 3 and 6% recorded significantly (P≤ 0.01) the highest fodder yield and indicated similarity in fodder yield with the application of 9% kaolin. Lower fodder yield at control shows statistical similarity in applying 9% kaolin.

Table 5. Fodder and Grain Yield (kgha-1) of Soybean as Affected by Variety, Growth Stage of Foliar Applied Kaolin and its Rate at BUK and Kadawa during the 2020 Dry Season.

Treatment	Grain Yield (kgha-1)		Fodder Yield (kgha-1)	
	BUK	Kadawa	BUK	Kadawa
Variety (V)				
TGX1835-10E	2295.8	2356.4	3919.7b	4747.9
TGX1955-4F	2508.9	2518.1	5542.7a	5156.7
P-Value	0.459	0.6194	0.058	0.214
SE (±)	234.38	277.85	408.05	185.41
Growth Stage (GS)				
Node Initiation	2028.2b	2074.7b	4405.9	4880.3ab
Flower Initiation	2569.9a	2283.4b	5185.4	5485.0a
Pod Initiation	2608.9a	2953.7a	4602.3	4491.6b
P-Value	0.012	0.0046	0.133	0.031
SE (±)	162.05	192.87	354.22	326.12
Kaolin Rate (R)				
0%	2120.9c	2086.8b	3394.0c	3860.5b
3%	2615.0ab	2965.9a	5368.2ab	5506.6a
6%	2688.4a	2657.9a	5849.5a	5604.2a
9%	2185.1bc	2038.4b	4313.1bc	4837.9
P-Value	0.001	0.001	0.001	0.002
SE (±)	181.73	118.30	393.86	377.64
Interaction				
V* GS	0.211	0.4361	0.387	0.559
V*R	0.481	0.8318	0.151	0.635
GS *R	0.645	0.3533	0.807	0.122
V* GS *R	0.659	0.1137	0.739	0.437

Means along the same column with unlike letter (s) are different at 5% level of probability.

DISCUSSION

Response of Soybean Varieties

The variety made not significantly record differences in the number of pods plan-1, hundred seed weight (g), and grain yield (kg ha-1) and was attributed to the ability or efficacy of the varieties to respond or use the environmental resources equally, put together it could be linked to a same genetic constituent. The effect of variety on fodder yield recorded significant differences at BUK. TGX1955-4F recorded more fodder yield (5542.7) than TGX1835-10E (3919.7). This could be due genetic composition and efficacy of TGX1955-4F, which was higher in fodder yield in the utilization of the available resources better than TGX1835-10E, which is lower. It agreed with the assertion made by Richburg et al. (2006) that varieties behaved differently due to differences in their genetic makeup and response to soil water use efficiency and even from year to year or field to field.

Response of Soybean to Foliar Applied Kaolin at Growth Stage

As revealed from the study, number of pods plan-1, hundred seed weight (g), grain, and fodder yield (kg ha-1) were significantly affected by kaolin application at the growth stage. Kaolin applied at flower and pod initiation indicated a higher value than application at node initiation. This could be because the application was at the right stage of crop development which reduced stress and affected yield components. This agrees with the; water stress in soybean is particularly damaging during flowering, pod setting, and grain filling. It reduces yield by lessening the number of pods, seeds, and seed weight Pedersen and Lauer (2004), which is worsened by a simultaneous temperature stress Hatfield and Prueger (2011), Wiebbecke et al. (2012).

Response of Soybean to Rates of Foliar Applied Kaolin

The result indicated that rates of foliar applied to kaolin significantly affected the yield and yield components of irrigated soybean across locations. A higher number of pods plan-1, hundred seed weight (g), grain, and fodder yield were recorded in the application of 3 and 6% kaolin and lower at the control and 9% kaolin. This suggests that the effectiveness of foliar-applied kaolin depended on the optimum rate. This was supported by El-mohsen et al. (2013), finding that kaolin 3% was more effective than kaolin 5%. However, applying the optimum kaolin rate favored the crop to grow and develop better morphology from which a higher yield could be obtained, and it was in agreement with the statement of Rania et al. (2018); it was evident that, in comparison to the control, foliar spraying of kaolin especially with kaolin at the rate of 6% caused a significant increase in seed yield during the two growing seasons. The lower value recorded in the application of 9% kaolin was attributed to an adverse effect of the coating of leaves that was formed by a thick dried solution of kaolin which could affect crop performance and final yield. This was in line with the assertion made by Davenport et al. (1969) that coatings formed by kaolin on leaf surfaces may curtail photosynthesis on overcast days when light is limited. From the control rate lower value was recorded and was attributed to stress due to lack of treatment hence more heat load on leaf surfaces, thereby causing a higher transpiration rate and affecting the final yield. This was supported by the finding of Rania et al. (2018) it was evident that, in comparison to the control, foliar spraying of kaolin, especially at the rate of 6% caused a significant increase in seed yield during the two growing seasons. The interaction of variety and growth stage of foliar-applied kaolin produced a plant with significantly more pods plant^{-1} and seed pod^{-1}.

Interactions

Interaction between variety and application at the growth stage could be due to variation in response of the variety to new management practice (application of kaolin), which reduced stress and affected final yield. It was in agreement with Taiz & Zeiger (2002) that additional water savings for increasing water use efficiency could be achieved by careful management.

Interaction of variety and kaolin rates was recorded on number of pods plant^{-1} and could result from one variety being more responsive to kaolin rate than the other. A similar report was made by Rania et al. (2018). It was evident that, compared to the control, foliar spraying of kaolin, especially at the rate of 6%, caused a significant increase in seed yield during the two growing seasons.

Interaction of application at the growth stage and kaolin rates significantly showed a greater number of pods plant^{-1}, seeds pod^{-1}, and hundred seeds weight (g) and was attributed to the application of kaolin at one growth stage was more effective than the other, put together could be due to application of optimum rate. However, foliar-applied kaolin at all growth stages indicated higher values at 3 and 6% rates. Fodder yield and grain yield application at flower initiation indicated higher values. It could be the reason for the significant interaction; hence, the crop was at the peak vegetative stage at the flowering stage, which coincided with the application optimum kaolin rate. On the other hand, a lower value at pod initiation was associated with the reproductive stage, while nod initiation could be due to poor crop establishment. This result was supported by the findings of Rosolem (2005), who stated that water demand for soybean is highest at the initiation of flowering. However, the most critical stage is a water deficit from pod initiation (R3) until 50% yellow (R7).

CONCLUSION

According to the findings of this trial, TGX1955-E recorded the highest grain yield (kg ha^{-1}), and lower values were from TGX1835-4F. The highest grain yield (kg ha^{-1}) was recorded in kaolin application at pod initiation, followed by the application at flower initiation, and lowest from the application at node initiation. Rates of 3 and 6% recorded higher fodder and grain yield and lower application of 9% and control rates across locations. The present study could recommend applying 3 and 6% at pod initiation to get higher grain and fodder yield (kg ha^{-1}); further research could be conducted to find the optimum with more varieties.

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DISCLOSURE STATEMENT

The author declares no competing interests

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