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RESEARCH ARTICLE

Physiological response of soybean (*Glycine max* L. Merrill) to foliar applied kaolin under irrigation in Sudan savanna of Nigeria

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ABSTRACT

A field experiment was conducted during the hot, dry season of 2019 in the Sudan savanna of Nigeria to evaluate the effect of foliar-applied antitranspirant (kaolin) on growth, yield, and yield components of irrigated soybean [*Glycine max* (L.) Merrill]. Teaching and Research Farm of the Faculty of Agriculture Bayero University, Kano and Irrigation Research Station, Kadawa, Kano, under the Institute for Agricultural Research Ahmadu Bello University Zaria, Kaduna, represented the two locations. Treatments consisted of two varieties of soybean (TGX1835-10E and TGX1955-4F), three growth stages of foliar applied kaolin, and four application rates (0%, 3%, 6%, and 9% w/v %). The factors were 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. Cultural practices, soil physical and chemical analysis, and irrigation were conducted. Data collected from physiological parameters included intercepted photosynthetically active radiation, leaf chlorophyll content, stomatal conductance, and plant dry matter (g), were subjected to analysis of variance using Statistix-10 and significant means of treatments were separated using Tukey HSD at a 5% level of probability. The result revealed that variety and foliar applied kaolin at growth stages and its rates significantly affected the physiological parameters of irrigated soybeans. The highest physiological responses were recorded from TGX1955-4F and lower from the variety TGX1835-10E. Foliar applied kaolin at pod initiation, and kaolin rates of 3 and 6% indicated the highest effect on measured physiological parameters and grain yield.

INTRODUCTION

Soybean [*Glycine max* (L.) Merrill] is a member of the family Fabaceae, genus Glycine, and species G. max. The crop is grown from seed, planted in rows in the field, and can grow well on various soils and climates. Soybean development is influenced by soil and climatic variables, particularly temperature, moisture, and day length (Raemekers, 2011). Soybean is a multipurpose crop, and its importance ranges from its use in human consumption, milk production, oil processing, medicine, industrial, income, poultry, livestock feeds, and soil management. The multiple functional status of the crop created a wide gap between demand and supply for the rapidly growing population. In the study area, crop production is at present majorly during the wet season, which is associated with high risk and uncertainty due to incidences of pest and diseases and climatic variables that affect crop performance, and the final yield of crops are unpredictable in the wet season. Although better performances and final yield in soybean are possible under irrigation in the study area, this could be constrained by the high transpiration rate and major abiotic stress on the crops.

A high rate of transpiration at any stage of crop development is a stress which receives less attention and has something to do with the development of the plants and is enough to cause adverse effects on soybean yield in the Sudan savanna of Nigeria. Although plants have various mechanisms to increase resistance to transpiration rate, artificial methods are often used to reduce the menace of excessive rate. Reducing crop luxury transpiration is essential for improving water productivity (Kang et al., 2017). Antitranspirant (kaolin) spray on plant leaves was found to decrease leaf temperature by increasing leaf reflectance and reducing transpiration rate more than photosynthesis in many plant species grown at high solar radiation levels (Nakano & Uehara, 1996). Because of the effect of a high transpiration rate on crop growth and final yield during the dry season in the Sudan savanna, there has been much interest in finding ways to reduce the rate of water losses through high transpiration. However, using kaolin as an antitranspirant would only be effective when appropriate and/or better variety, at the right growth stage and correct rates, are used. Therefore, this research aims to evaluate the effect of foliar-applied kaolin on the physiological response of irrigated soybean.

MATERIALS AND METHODS

The experiment was conducted during the dry season of 2019 in Sudan savanna of Nigeria at the Teaching and Research Farm of the Faculty of Agriculture Bayero University, Kano (11^0 97' 98.6" N, 8^0 42' 03.7" E) and Irrigation Research Station, Kadawa (11̊ 39' 0.120"N 8̊ 50' 6"E). Treatments consisted of two varieties of soybean, three growth stages of foliar applied kaolin (node, flower and pod initiation) and four rates of kaolin indicated them. The factors were 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 sub plots and kaolin rates in sub-sub plots.

TGX1835-10E and TGX1955-4F are known for resistance to pest and diseases, high yielding and good for 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 of the experimental site was marked out in to total size of 1150.5m^2. It was divided in to three replications with an alley of 2m between. Replications were transformed in to main, sub and sub-sub plots of 3m by 5m with an alley of 0.75m between each. Main plot, sub-plot and sub-sub plot consisted of 4 ridges of 5m by 0.75m (15m^2) and net plot sizes (two inner rows) 4.5m^2.

Sowing was observed manually by hand on four ridges side, 6 seeds per hole and were thinned to 4 plants at 3WAS. Spacing between ridges was 0.75m^2 and 10cm between stands with depth of about 3 to 4 cm. Supplying was donned at 10 days after sowing. Through surface flooding, irrigation water was conveyed in to basin of research plots. Interval of four days between irrigation was maintained in BUK and 7day in Kadawa due to variation in water table and withdrew at pods maturity. Powdered, water soluble kaolin was sieved and diluted in water in to different rates (0%, 3%, 6% and 9% w/v) and applied on leaves surfaces. The rates were obtained through;

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).

Data Collection and Analysis

Two inner rows were used for sampling; five plants were randomly tagged from which data were collected; Intercepted Photosynthetically Active Radiation (μmol quanta $m^{-2} s^{-1}$) values were obtained from five tagged plants leaves in each plot at 6, 9 and 12WAS using leaf Chlorophyll meter (Minolta SPAD 502). Leaf Chlorophyll Content (umolm^{-2}) were obtained from five tagged plants leaves in each plot using leaf Chlorophyll meter on the upper layer of two well displayed leaves (Minolta SPAD 502). Stomatal Conductance (mmol $m^2 s^1$) were determined at 6, 9, and 12WAS using leaf photometer (Decagon SC-1, 2010). Dry Matter Weight (g) Plant^{-1} were obtained after uprooting four plants from border rows, roots rinsed in water dried, paper wrapped, and oven-dried while the average was recorded. The data were subjected to analysis of variance (ANOVA) using Statistix-10. Significant treatment means were separated using Tukey HSD at 5% probability level.

RESULTS

Results of the recorded intercepted photosynthetic active radiations (IPAR) on soybean as influenced by variety, growth stage of foliar applied kaolin, its rate, and their interaction at BUK and Kadawa during the 2019 dry season are presented in (**Table 1**) and across sampling periods, and locations variety recorded no significant effect exception at 12WAS at Kadawa where variety TGX1955-4F significantly ($P \leq 0.05$) recorded higher IPAR than variety TGX1835-10E). The effect of foliar applied kaolin at the growth stage of irrigated soybean showed a significant ($P \leq 0.01$) effect at 12WAS at Kadawa. At par, higher IPAR was recorded in the kaolin application flower and pod initiation and lower IPAR in the application at node initiation. The effect of kaolin rates indicated a significant ($P \leq 0.01$) effect at 6 and 12WAS and recorded higher IPAR at control, 3, and 6% rates and lower IPAR at 9% rate at BUK. At 9WAS, application of 3% was higher in IPAR and was statistically similar with IPAR recorded at the control and 6% rates. The lower IPAR recorded at a 9% rate in 9WAS was also statistically similar to IPAR recorded at the control and 6% rates.

The interaction of growth stages of foliar applied kaolin and its rates at 12WAS from Kadawa was significant ($P \leq 0.05$) **(Table 2),** and the highest IPAR that was recorded at 6% rate from flower and pod initiations was statistically similar with IPAR from all other rates and growth stages except at 9% rate at node initiation which recorded lower IPAR and was in turn, statistically similar in IPAR with other rates and growth stages.

Table 1 presented the study's result on soybean leaf chlorophyll content as affected by variety, the growth stage of foliar-applied kaolin, and its rate. The result indicated that variety had no significant effect on leaf chlorophyll content across the sampling periods and locations except at 6 and 9WAS at BUK where TGX1955-4F significantly recorded values than TGX1835-10E. The growth stage of foliar-applied kaolin showed no significant effect across the sampling periods and locations except at 12WAS at Kadawa, which significantly showed higher leaf chlorophyll content in kaolin application at pod and flower initiation and lower values at node initiation. Effects of kaolin rates on leaf chlorophyll content recorded significant ($P \leq 0.05$) effects at 9 and 12WAS at Kadawa. The rate of 3% at 9WAS and 3 and 6 % at 12WAS recorded higher values, which are statistically similar to leaf chlorophyll content recorded at the control and the 3% rate at 9WAS. The 9% rate at 9WAS was at par with the control at 12WAS. Similarly, the control and 3% rate at 9WAS were similar. However, the lowest leaf chlorophyll content was recorded at a 9% rate in 12WAS.

The interaction between the variety and growth stage of foliar-applied kaolin at BUK at 6WAS was significant ($P \leq 0.05$) (**Table 3**). Higher leaf chlorophyll content was recorded from control in TGX1955-4F and was similar to all other growth stages and varieties except TGX1835-10E, which indicated lower leaf chlorophyll content at node initiation. The trend was statistically similar with all other growth stages of foliar-applied kaolin except at node initiation from TGX1955-4F, which recorded higher leaf chlorophyll content.

The interaction between variety, the growth stage of foliar-applied kaolin, and its rates showed a significant ($P \leq 0.05$) effect at 9WAS at BUK (**Table**

4). TGX1835-10E at 3% and variety TGX1955-4F at 3% and 6% recorded higher leaf chlorophyll content at node and pod initiation, respectively. They were statistically similar in leaf chlorophyll content across varieties, sampling periods, and kaolin rates except for TGX1955-4F at 6% at flower and TGX1835-10E at 9% flower initiation, which recorded lower leaf chlorophyll content. However, the result indicated similarities in leaf chlorophyll content recorded from varieties, sampling periods, and rates except for TGX1835-10E and TGX1955-4F at 3% and 6% at node and pod initiation, respectively.

The significant ($P \leq 0.01$) interaction between variety, growth stages, and kaolin rates in (**Table 5**) at 6WAS indicated higher leaf chlorophyll content from TGX1955-4F applied at pod initiation at 3 and 6% rates and lower values from TGX1835-10E at 9% rate applied at node initiation.

The effects of variety, the growth stage of foliar-applied kaolin, and its rates on stomatal conductance (mmol m2 s1) of soybean at BUK during the 2019 dry season are presented in (**Table 6**). The soybean variety had no significant influence on the stomatal conductance of soybean across the sampling periods and locations. The growth stage of foliar-applied kaolin recorded a significant ($P \leq 0.05$) effect on the stomatal conductance of soybean at BUK. Higher stomatal conductance was observed when applied at flower initiation at 9 and 12WAS at BUK and was statistically similar with values at 9 and 12WAS with kaolin applied at pod initiation. Although lower stomatal conductance was recorded with the application at node initiation at buk at 9 and 12WAS, statistically, similar values were recorded with the application at 9 and 12WAS at BUK.

Rates of foliar-applied kaolin showed a significant ($P \leq 0.01$) effect at 9 and 12WAS at BUK and 12WAS at Kadawa. Kaolin rates at 3 and 6% recorded higher stomatal conductance at 9 and 12WAS at BUK and at 12WAS at Kadawa. The higher stomatal conductance recorded was statistically similar to stomatal conductance recorded in the control at12WAS at BUK and at 6 and 9% rates at Kadawa, statistically similar stomatal conductance recorded at 3 and 6% rates in 9 and 12WAS. Although control and 9% rates in 9WAS and 9% at 12WAS recorded the lowest stomatal at BUK and the control rate at Kadawa statistically was similar to control rate at BUK at 12WAS and at 6 and 9% rates at Kadawa at 12WAS.

The influence of variety, the growth stage of foliar-applied kaolin, and kaolin rates on soybean dry matter weight (g) at 12WAS at BUK and Kadawa during the 2019 dry season is presented in (**Table 6**). The study indicated that the variety and growth stage of foliar-applied kaolin significantly affected the dry matter weight of soybean at Kadawa. Statistically, TGX1955-4F significantly ($P \leq 0.05$) recorded a higher dry matter weight of soybean than TGX1835-10E. However, kaolin application at node and flower initiations significantly ($P \leq 0.05$) indicated more dry matter weight than application at pod initiation, which was lower. Rates of foliar-applied kaolin showed a significant ($P \leq 0.01$) effect across the locations. At BUK, 3% rate indicated the highest dry matter weight and at 6% rate at Kadawa and similar dry matter weight at 6% rate at BUK. However, lower dry matter weight was recorded at the control and 9% at BUK and 3% rate at Kadawa, but similar values were obtained at 6% rate at BUK and at 9% rate at Kadawa. The lowest dry matter weight was recorded at the control rate at Kadawa though statistically similar, with values at 9% rate in the same location.

DISCUSSION

Physiological Response of Soybean Varieties

The significant effect of variety in recorded intercepted photosynthetically active radiation, leaf chlorophyll content, and dry matter observed due to kaolin application could be due to chance, or one variety had the advantage of having the efficacy of utilizing the environmental resources and location than the other. Put together could be the due effect of genetic composition. Moreover, Lombardini et al. (2005) observed a positive effect on the chlorophyll index after treatment with kaolin on matured pecan trees. Khalil (2006) reported that antitranspirant reflecting significantly increased all growth parameters of sesame (*Sesamum indicum* L.) plants compared with the control treatment.

Physiological Response of Soybean to Foliar Applied Kaolin at Growth Stage

Significance differences were recorded from irrigated soybeans due to foliar-applied kaolin at the growth stage. A significant effect was recorded on intercepted photosynthetically active leaf chlorophyll content, stomatal conductance, and plant dry matter. The effect was higher in kaolin application at flower and pod initiation and lower at node initiation.

Table 1. Intercepted Photosynthetically Active Radiation (μmol quanta m^{-2} s^{-1}) and Leaf Chlorophyll Content of Soybean as Affected by Variety, Growth Stage of Foliar Applied Kaolin and Kaolin Rate at BUK and Kadawa during the 2019 Dry Seasons.

Treatment	BUK (IPAR)			Kadawa (IPAR)			BUK (CHL)			Kadawa (CHL)		
	6WAS	9WAS	12WAS	6WAS	9WAS	12WAS	6WAS	9WAS	12WAS	6WAS	9WAS	12WAS
Variety (V)												
TGX1835-10E	438.8	525.2	533.7	445.7	488.1	519.9b	25.93b	30.19b	31.25	29.60	32.09	36.75
TGX1955-4F	419.9	525.8	523.3	410.8	503.3	526.4a	29.16a	31.81a	34.52	30.27	33.28	37.37
P-Value	0.102	0.923	0.060	0.083	0.068	0.048	0.005	0.035	0.187	0.510	0.072	0.416
SE (±)	6.59	5.06	2.64	10.76	4.99	3.87	0.231	0.308	1.654	0.841	0.339	0.616
Growth Stage (GS)												
Node Initiation	421.2	530.2	524.3	400.4	444.9	504.1b	28.15	29.45	31.90	30.59	31.11	34.65b
Flower Initiation	441.1	530.3	525.1	451.9	530.9	531.3a	26.87	31.83	34.23	29.73	33.94	38.64a
Pod Initiation	425.5	515.8	536.2	432.5	514.8	533.9a	27.62	31.72	32.52	29.49	33.02	37.89a
P-Value	0.358	0.075	0.437	0.062	0.002	0.003	0.721	0.201	0.308	0.711	0.149	0.053
SE (±)	13.69	6.22	9.80	18.39	16.26	9.51	1.558	1.355	1.454	1.385	1.311	1.441
Kaolin Rate (R)												
0%	456.5a	527.9ab	535.2a	436.5	493.7	517.3	27.70	31.04	32.41	29.08	31.84ab	36.27b
3%	436.6a	530.9a	533.8a	424.4	506.4	529.9	28.42	31.35	32.98	30.10	33.30ab	39.16a
6%	428.8a	528.6ab	534.8a	431.6	497.3	537.3	25.39	31.61	34.73	30.33	34.89a	39.41a
9%	395.2b	514.6b	510.2b	420.7	491.5	507.9	28.67	30.00	31.40	30.24	30.73b	33.38c
P-Value	0.001	0.037	0.002	0.711	0.185	0.066	0.223	0.062	0.124	0.807	0.029	0.001
SE (±)	11.29	5.87	5.98	14.79	7.15	9.34	1.704	1.100	1.378	1.444	1.389	0.989
Interaction												
V* GS	0.369	0.259	0.968	0.574	0.293	0.776	0.039	0.475	0.479	0.842	0.766	0.566
V*R	0.176	0.641	0.550	0.071	0.752	0.319	0.427	0.489	0.456	0.537	0.906	0.526
TA*R	0.940	0.762	0.247	0.186	0.753	0.048	0.109	0.307	0.102	0.333	0.775	0.095
V* GS*R	0.449	0.452	0.605	0.611	0.470	0.592	0.999	0.032	0.205	0.023	0.172	0.638

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

Table 2. Interaction between Growth Stage of Foliar Applied Kaolin and Kaolin Rate on Intercepted Photosynthetically Active Radiation (μmol quanta m^{-2} s^{-1}) of Soybean at Kadawa during Dry Season

Kadawa	Rate 12WAS			
	0%	3%	6%	9%
Growth Stage				
NODIN	481.37ab	529.52ab	528.77ab	476.83b
FLOIN	532.95ab	527.10ab	541.48a	523.77ab
PODIN	537.67ab	533.32ab	541.53a	523.15ab
SE (±)			16.174	

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

Table 3. Interaction between Variety and Growth Stage of Foliar Applied Kaolin on Leaf Chlorophyll Content (umolm^{-2}) of Soybean at BUK Dry Season.

BUK	Growth Stage 6WAS		
	NODIN	FLOIN	PODIN
Variety			
TGX1835-10E	23.90^{b}	25.66^{ab}	28.24^{ab}
TGX1955-4F	32.40^{a}	28.08^{ab}	26.99^{ab}
SE (±)	2.204		

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

Table 4. Interaction between Variety, Growth Stage of Foliar Applied Kaolin and Kaolin Rate on Leaf Chlorophyll Content (umolm^{-2}) of Soybean at buk during Dry Season.

		Rate 9WAS			
		0%	3%	6%	9%
Variety					
TGX1835-10E	NODIN	29.76^{ab}	33.81^{a}	30.10^{ab}	31.31^{ab}
	FLWIN	31.2^{ab}	31.13^{ab}	33.61^{ab}	21.13^{b}
	PODIN	31.17^{ab}	27.93^{ab}	31.47^{ab}	29.50^{ab}
TGX1955-4F	NODIN	31.22^{ab}	28.23^{ab}	30.00^{ab}	31.33^{ab}
	FLWIN	31.43^{ab}	32.32^{ab}	21.13^{b}	29.67^{ab}
	PODIN	31.45^{ab}	34.67^{a}	34.83^{a}	32.70^{ab}
SE (±)		2.695			

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

Table 5. Interaction between Variety, Growth Stage of Foliar Applied Kaolin and Kaolin Rate on Leaf Chlorophyll Content (umolm^{-2}) of Soybean at 6 WAS at kadawa Dry Season.

Kadawa		Rate 6WAS			
		0%	3%	6%	9%
Variety					
TGX1835-10E	NODIN	34.0^{ab}	28.19^{a-f}	32.90^{a-d}	24.43^{f}
	FLWIN	24.65^{ef}	30.77^{a-f}	27.93^{b-f}	35.65^{a}
	PODIN	29.99^{a-f}	30.49^{a-f}	30.62^{a-f}	25.897 $^{de-f}$
TGX1955-4F	NODIN	26.79^{c-f}	32.37^{a-f}	32.37^{a-e}	26.79^{c-f}
	FLWIN	29.59^{a-f}	29.64^{a-f}	29.47^{a-f}	30.13^{a-f}
	PODIN	29.71^{a-f}	29.17^{ab-f}	28.70^{a-f}	31.33^{a-f}
SE (±)			3.538		

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

Table 6. Stomata Conductance (mmol m^2s^1) and Dry Matter (g) at 12WAS of Soybean as affected by Variety, Growth Stage of Foliar Applied Kaolin and Kaolin Rate at BUK and Kadawa during the 2019and 2020 Dry Seasons.

Treatment	BUK (STC)			Kadawa (STC)			12WAS	
	6WAS	9WAS	12WAS	6WAS	9WAS	12WAS	BUK (DM)	Kadawa (DM)
Variety (V)								
TGX1835-10E	0.31	0.40	0.57	0.29	0.49	0.65	68.41	69.83b
TGX1955-4F	0.28	0.37	0.50	0.27	0.46	0.59	78.93	90.55a
P-value	0.146	0.192	0.273	0.264	0.070	0.169	0.187	0.037
SE (±)	0.010	0.011	0.046	0.039	0.011	0.029	5.335	5.518
Growth Stage (GS)								
Node Initiation	0.28	0.36b	0.47b	0.27	0.45	0.58	69.93	83.59a
Flower Initiation	0.33	0.41a	0.58a	0.29	0.50	0.66	80.28	83.17a
Pod Initiation	0.29	0.39ab	0.55ab	0.28	0.47	0.61	70.79	73.06b
P-Value	0.235	0.052	0.033	0.106	0.062	0.146	0.244	0.039
SE (±)	0.025	0.019	0.033	0.015	0.020	0.037	6.246	2.187
Kaolin Rate (R)								
0%	0.29	0.35b	0.52ab	0.28	0.47	0.58b	65.22b	73.68c
3%	0.31	0.42a	0.59a	0.27	0.48	0.63a	84.53a	81.69b
6%	0.31	0.41a	0.57a	0.27	0.47	0.61ab	77.97ab	89.41a
9%	0.28	0.36b	0.47b	0.29	0.48	0.63ab	66.94b	77.97bc
P-Value	0.422	0.001	0.003	0.087	0.950	0.150	0.001	0.010
SE (±)	0.018	0.016	0.027	0.012	0.018	0.025	5.021	2.349
Interaction								
V* GS	0.916	0.062	0.246	0.087	0.591	0.379	0.660	0.3110
V*R	0.398	0.668	0.282	0.995	0.932	0.784	0.359	0.7021
TA*R	0.956	0.996	0.433	0.422	0.116	0.070	0.175	0.7865
V* GS*R	0.988	0.674	0.917	0.942	0.933	0.926	0.219	0.3680

The reasons could be due to the established rooting system, number of branches plant^{-1}, wider or broader of leaves, and wider leaf area index hence lighter intercept for photosynthesis, in addition to light interception, temperature and nutrient uptake, which could make growth hormones work at optimum. The effect of kaolin application at the growth stage of irrigated soybean significantly indicated that application at flower initiation recorded more plant dry matter, followed by the application at node initiation, while values were recorded at pod initiation. The reason could be linked to crop physiological stage of the crop with the application at node initiation; the crop was less developed in terms of rooting system, the number of leaves, and sizes than at flower initiation and pod initiation; it could be due to the influence of reproductive phase. This result agrees that different water savings for increasing water use efficiency can be achieved through careful management (Taiz & Zeiger, 2002).

Physiological Response of Soybean to Rates of Foliar Applied Kaolin

Significant physiological response of soybean was observed due to rates of foliar applied kaolin across sampling periods and locations. Intercepted photosynthetically active radiation, leaf chlorophyll content, stomatal conductance, and plant dry matter were observed to be highest at 3 and 6% and lower at the control and 9%. The highest physiological values (intercepted photosynthetically active radiation) due to the application of 3 and 6% kaolin rates could be due to low heat stress due to the application of optimum kaolin rate, and this was in consonant with the statement of Rosati et al. (2006), Wünsche et al. (2004), Shellie and King (2013) that kaolin applied at a high concentration reduces the availability of IPAR. Differences in leaf chlorophyll content are supported by a study made by Lombardini et al. (2005), who observed a positive effect on the chlorophyll index after kaolin treatment on a mature pecan tree. Applying kaolin at 3 and 6% rates recorded more dry matter plant-1 and was attributed to less stress due to applying the optimum rate. This statement was in line with that of Jifon and Syvertsen (2003) and Roussos et al. (2010), who reported that kaolin clay treatments resulted in higher plant height and plant dry weight, which could be attributed to the reduced water loss due to the reduction of leaf temperature resulting in lower transpiration and higher water use efficiency. The lower effect recorded at a 9% rate was attributed to the negative effect of coating that was formed by a thick dry solution of kaolin, and its effect was found to have affected crop performance due to reduced photosynthesis on overcast days when light is limited, and it 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 effects were recorded. They were attributed to stress due to no application of kaolin and more heat load on leaf surfaces, causing a higher transpiration rate. A higher rate of transpiration is stressed, making cells flaccid and leading to leaf or plant wilting. This could be why the leaf chlorophyll content, intercepted photosynthetically active radiation, and stomatal conductance was lowest. This result was supported by Rosati et al. (2006), who reported that the foliar application of kaolin had been evaluated for its ability to reduce the adverse effects of water stress and improve plants' physiology and productivity. In another assertion, foliar spray with kaolin positively affected plant height, total dry weight, and water use efficiency (Segura-Monroy et al., 2015).

The interaction of the growth stage and kaolin rates significantly showed more IPAR. It was attributed to the application of kaolin at one growth stage being more effective than the other stage due to the optimum kaolin applied. This was in agreement with Taiz and Zeiger (2002) that different water savings for increasing water use efficiency can be achieved by careful management. The interaction of variety and growth stage of applied kaolin had significantly more leaf chlorophyll content. It could be due to genetic differences between the two varieties, which also affected the response of the two varieties to foliar spray of kaolin at the different growth stages, and it was agreed with Taiz and Zeiger (2002) that different water savings for increasing water use efficiency could be achieved through manipulation management practices. Interaction of variety, growth stage, and kaolin rates of foliar applied kaolin had significantly recorded more leaf chlorophyll content. This result could be due to the response of variety to the application of optimum rate and at the correct growth stage and it was in line with the assertion made by; Glenn et al., (2005), Shellie and Glenn (2008), Glenn (2009), Roussos et al. (2010), and Denaxa et al. (2012) that the effectiveness of kaolin is linked to plant species and cultivars. It also agreed with the assertion made by Richburg et al. (2006) that varieties behave 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.

CONCLUSION

According to the findings, TGX1955-E recorded the highest grain yield (kg ha^{-1}), and lower values were recorded on TGX1835-4F. Higher grain yield (kg ha^{-1}) was recorded from kaolin application at pod initiation, followed by flower initiation, and lowest from the application at node initiation. Rates of 3 and 6% recorded higher fodder and grain yield (kg ha^{-1}), while lower values were obtained from 9% and the control rates across the locations and seasons. Foliar application of 3 and 6% kaolin at the node and flower initiation of soybean under irrigation could be recommended for the farmers. This study suggested that further study with the application of 3, 4, 5, and 6% to find the optimum could be carried out.

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CONFLICT OF INTERESTS

The authors declare no conflict of interests.

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