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Comparative Growth and Grain Yield Responses of Early and Late Soybean Maturity Groups to Induced Soil Moisture Stress at Different Growth Stages

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Abstract: Pot experiment was conducted at the University of Ilorin, Ilorin, Nigeria to comparatively assess the response of the early and late maturity soybean groups to induced moisture stress at three growth stages (vegetative, flowering and pod-filling). Significant differences were obtained between the early and late maturity groups in all growth parameters, yield components and grain yield measured. Leaf production, branching, plant height, dry matter production, crop growth rate and relative growth rate were higher in late than in the early maturity group. Soil moisture stress occurring at any growth stage resulted in significant decreases in leaf production, plant height, branching, dry matter production crop growth rate and relative growth rate. The decreases were greater with stress occurring at the vegetative and flowering growth stages. Grain yield was significantly reduced by soil moisture stress, especially when it occurred at the vegetative and flowering growth stages, by reducing number of pods produced per plant, shelling percentage, harvest index and increasing floral and pod abortion. Significant interactions between maturity type and period of moisture stress revealed that soil moisture stress occurring at both the vegetative and pod-filling stages are more critical to plant growth and seed production in the late maturing genotypes, while both the vegetative and flowering stresses are more critical for the early maturing genotypes.

Key words: Moisture stress · growth stages · maturity groups responses · soybean

INTRODUCTION

Soybean (*Glycine max* (L.) Merrill) is one of the most important edible grain legumes in the world due to high nutritional value and high seed protein content (38-42 %) [1]. The crop which was first introduced to Nigeria in 1908 [2] is gradually becoming an important crop in the country due to increasing demand for edible oil and protein which has led to the expansion of soybean production, especially in the savanna ecological zone, an area characterized by erratic and low rainfall pattern [3] and hence prone to drought stress. Many varieties have been produced by introduction, breeding and selection and with the release of outstanding ones for large scale production in different ecological zones [4]. Nevertheless, evidence available indicated that yield on farmers' farms are very low [5], due to many reasons [6], especially low and poorly distributed rainfall [3, 7].

Insufficient water, especially during emergence, flowering and pod-filling stages lower the yield of soybean [8-10]. Drought stress is a serious problem in the semi arid region of West Africa and it can occur at any time during cropping season. Many aspects of plant growth have been reported to be affected by drought stress, including leaf expansion which is reduced due to sensitivity of cell growth to water stress [11]. Reduction in leaf area reduces crop growth and hence biomass production. Seed production, which is positively correlated with leaf area may also be reduced by leaf area reduction induced by drought stress. It is known that moisture stress reduces soybean yield [12] and this effect is influenced by the timing and severity of the stress.

While there are on-going efforts in the development and release of improved, disease and pests resistant varieties [13] to replace the susceptible ones currently under cultivation, the problem of drought stress can be addressed through the knowledge of the response to moisture stress occurring at different stages during growth of different maturity groups. This study was therefore conducted to investigate the comparative response of early and late maturing soybean genotypes to induced moisture stress at different growth stages.

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MATERIALS AND METHODS

The study was conducted in a potted experiment at the Crop Pavilion, Department of Agronomy, University of Ilorin in the southern guinea savanna zone of Nigeria during the dry period of November, 2004 to April, 2005. The factorial experiment laid out in split-plot arrangement with varieties nested within maturity group, evaluated five genotypes each of early and late maturing soybean groups exposed to soil moisture stress at three growth stages (vegetative, flowering and pod-filling). The moisture stress treatments involved withholding watering for 14 days during (i) vegetative (2-4 weeks after planting); flowering (R1); and pod-filling (R4) (R1 and R4 are in accordance with Fehr *et al.* [14]. A well-watered control in which no stress was applied throughout the growing period was included in each of the four replicates used in the study.

Each experimental unit was a 15-litre pot filled with top soil, obtained from farm land adjacent to the pavilionand planted with ten seeds of the appropriate genotype and was later thinned to five seedlings per pot at 2 WAP. Each experimental unit received adequate watering from planting until the commencement of each stress period when watering was withheld for 14 days after which normal watering resumed till maturity. Weed management within the pots was achieved by hand pulling at two weekly intervals, while booster application of N was made to each experimental unit at 2 WAP at a rate of 40 kg N ha1. Before the commencement of the first stress period, two plants were tagged in each experimental unit and these were used for the measurement of non-destructive data which included leaf production, plant height, branching, floral and pod abortion (determined as the difference between number of pods at R4 (full podding) and R7 (maturity) [15]. The two plants were also harvested at maturity for yield components and grain yield determination. The remaining three plants in each pot were harvested at 3, 5 and 7 WAP for dry matter production which was used to estimate crop growth rate and relative growth rate at vegetative and reproductive growth stages. Dry matter production was measured by oven-drying the harvested plants at 80°C to constant weight. The growth indices, CGR and RGR were estimated according to Hunt [16].

$$CRG = \frac{W_2 - W_1}{t_2 - t_1}$$

$$RGR = \frac{In\ W_2 - Ln\ W_1}{t_2 - t_1}$$

Where W_1 and W_2 are dry matters at t_1 and t_2 respectively.

At maturity, the two tagged plants were harvested, oven-dried and weighed to obtain total above ground biomass yield. The plants were later processed to obtain number of pods at harvest, number of pods with grains, percentage aborted pods, shelling percentage, harvest index and grain weight. All data collected were subjected to analysis of variance using split-plot model with Genstat 5.3.2 Statistical package. Significant means were separated by the Duncan's Multiple Range Test at 5 percent probability level.

RESULTS

Effects on plant growth parameters

Leaf production: Leaf production showed significant ($p<0.001$) differences between the two maturity groups throughout the measurement periods. Similarly, time of stress application resulted in significant ($p<0.001$) differences in leaf production across the maturity groups. Number of leaves per plant was significantly lower in the early than in the late maturity groups (Fig. 1a). Figure 1b shows that moisture stress occurring during the vegetative growth stage significantly reduced leaf production throughout the measurement periods, while stress occurring at flowering stage significantly reduced number of leaves at 7 WAP.

Plant height: The two soybean maturity groups showed similar plant height ($p>0.05$). However, time of soil moisture stress resulted in significantly ($p<0.001$) different plant heights across the maturity groups. Early maturity group showed non-significantly taller plants than the late maturity groups between 3-4 WAP, but vice versa between 6-8 WAP (Fig. 2a). Moisture stress occurring at the vegetative and flowering growth stages resulted in significantly shorter plants, while stress occurring at pod-filling stage has no appreciable effect on plant height (Fig. 2b). Significant interactions between maturity group and stage of moisture stress application, showed that while stress occurring at both the vegetative and flowering stages reduced plant height in the early maturity group, only the vegetative stress significantly reduced height in the late maturity group (Table 1).

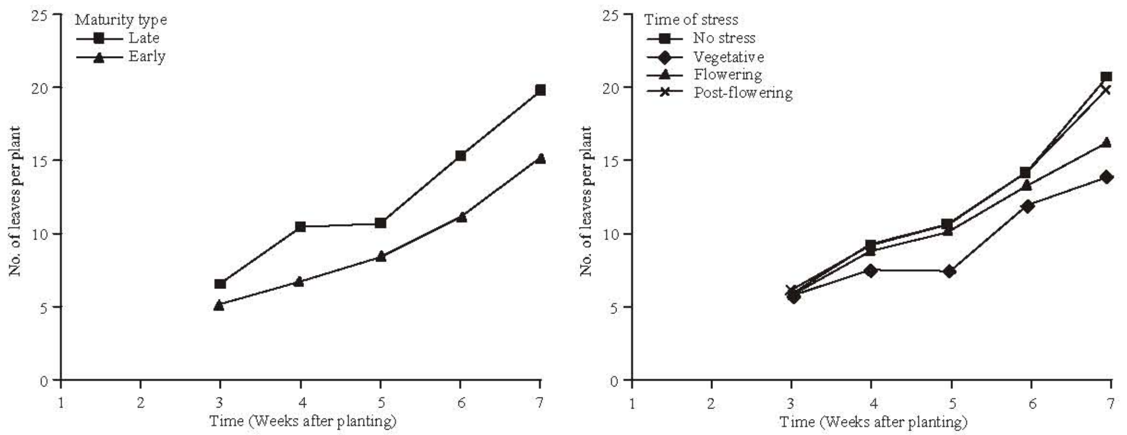

Fig. 1: Effect of (a) maturity type and (b) time of moisture stress on number of leaves in soybean

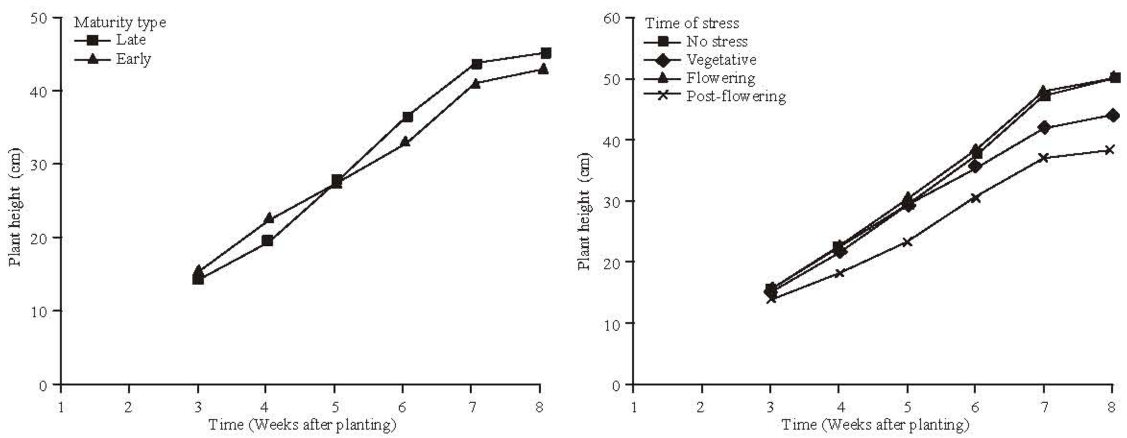

Fig. 2: Effect of (a) maturity type and (b) time of moisture stress on height of soybean

Table 1: Interactive effects of maturity type and time of moisture stress on plant height of soybean

		Weeks after planting					
Maturity	Stress period	3	4	5	6	7	8
Late	No stress	14.92bc	21.03bc	30.39a	40.15a	46.98a	49.10a
	Vegetative	14.13c	16.47d	20.74d	30.65d	37.97b	39.30b
	Flowering	14.20c	20.73bc	30.91a	36.90b	45.63a	47.42a
	Pod-filling	14.87bc	20.91bc	31.12a	40.94a	47.68a	48.87a
Early	No stress	15.91ab	24.23a	28.16b	34.24c	46.63a	49.54a
	Vegetative	13.89c	19.98c	25.48	30.46d	35.45b	36.77b
	Flowering	15.89ab	22.87ab	28.01	33.79c	37.96b	39.63b
	Pod-filling	16.59a	24.66a	29.75ab	35.59bc	47.58a	50.33a
	s.e.d	0.750	1.163	1.081	1.216	1.687	1.753

Figures followed by the same letter(s) in each column are not significantly different by Duncan's Multiple Range Test at 5 percent probability level

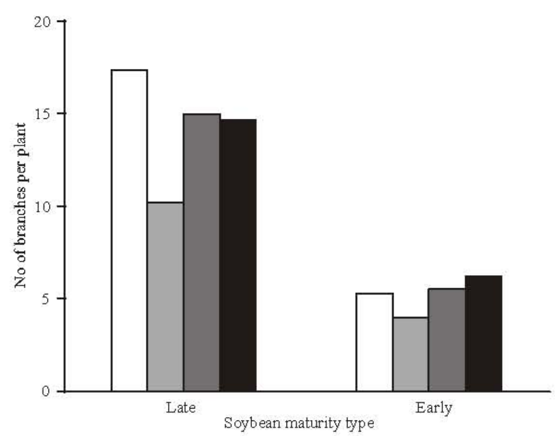

Fig. 3: Interactive effect of maturity type and time of moisture stress on branching of soybean

Branching: Branching was significantly affected by both the maturity group ($p<0.001$) and stage of stress application ($p<0.01$) and these were qualified by significant interaction effect. Figure 3 shows that number of branches per plant was significantly lower in the early than in the late maturity group at any stage of stress

Table 2: Interactive effects of maturity type and time of moisture stress on plant growth indices

Maturity	Stress period	RGR (veg.)	RGR (rep.)	CGR (veg.)	CGR (rep.)
Late	No stress	0.242a	0.034c	1.253a	0.680b
	Vegetative	0.160b	0.098a	0.589b	0.919a
	Flowering	0.261a	0.043c	1.045a	0.605bc
	Pod-filling	0.250a	0.031c	1.178a	0.511c
Early	No stress	0.096c	0.074b	0.084c	0.170d
	Vegetative	0.052e	0.035c	0.023c	0.030d
	Flowering	0.065de	0.032c	0.034c	0.034d
	Pod-filling	0.090cd	0.084ab	0.061c	0.176d
	s.e.d	0.0125	0.0099	0.1068	0.0774

Figures followed by the same letter(s) in each column are not significantly different by Duncan's Multiple Range Test at 5 percent probability level

Table 3: Interactive effects of maturity type and time of moisture stress on dry matter (g/plant) of soybean

		Weeks after planting		
Maturity	Stress period	3	5	7
Late	No stress	0.61a	18.12a	26.64a
	Vegetative	0.55a	6.04c	20.84c
	Flowering	0.43bc	14.92b	23.03b
	Pod-filling	0.51ab	17.00ab	24.00b
Early	No stress	0.39cd	1.43d	3.80d
	Vegetative	0.29d	0.60d	1.03e
	Flowering	0.35cd	0.84d	1.31e
	Pod-filling	0.33cd	1.18d	3.64d
	s.e.d	0.053	1.574	0.950

Figures followed by the same letter(s) in each column are not significantly different at 5 percent probability level by Duncan's Multiple Range Test

application. Across both maturity types, branching was reduced by moisture stress applied at any growth stage, although the difference was only significant with stress applied at the vegetative growth stage. Significant interactive effect revealed that moisture stress at any growth stage has no appreciable effects on branching in the early maturing type, while it significantly reduced branching in the late maturity group at any stage.

Growth indices: Crop Growth Rate (CGR) and Relative Growth Rate (RGR) measured at the vegetative and reproductive stages were significantly influenced by maturity group ($p<0.001$) and stage of stress application ($p<0.001$), with significant interaction effects ($p<0.001$). Both CGR and RGR at the two measurement periods were lower in the early than in the late maturity group across all moisture stress treatments. Soil moisture stress occurring at the vegetative growth stage significantly reduced CGR and RGR measured during the vegetative growth stage, while stress occurring at both flowering and pod-filling stages had no significant effects at this stage but reduced both indices measured at the reproductive stage. Significant interaction effects showed that RGR at both periods were significantly reduced by stress occurring at both vegetative and flowering stages in the early maturity group, while only stress at the vegetative stage reduced RGR in the late maturity group. Similar interaction effects showed that CGR at both measurement periods were not significantly affected by moisture stress at any growth stage in the early maturity group, while moisture stress at the vegetative growth stage significantly reduced CGR in the late maturity group (Table 2).

Dry matter production: Dry matter production was significantly affected by both the maturity group and stage of stress application ($p<0.001$). Significant interaction effects showed appreciably different responses of dry matter production in the maturity groups. Table 3 shows that dry matter production was significantly lower in the early than in the late maturity group. The table also shows that moisture stress occurring at both the vegetative and flowering growth stages significantly reduced dry matter production, while the pod-filling stress showed no appreciable effect. Significant interaction effects showed that while moisture stress at any growth stage significantly reduced dry matter in the early maturity group, pod-filling stress has no appreciable effect on the dry matter production in the early maturity group.

Effects on yield components and grain yield: Results of the analyses of variance for yield components and grain yield (Table 4) show that most yield components and grain yield were significantly influenced by soybean maturity group and stage of stress application. Most of these main effects were also qualified by significant interactions of maturity group by stage of moisture stress with the exception of number of flowers, percentage aborted pods and biomass yield. Number of flowers per plant was similar for the two maturity groups, while moisture stress occurring at any growth stage significantly reduced number of flowers across the maturity groups (Table 5). The table also shows that the number of pods at harvest was significantly higher in the early than in the late maturity group. Moisture stress ant

Table 4: Mean squares from the analyses of variance for yield components and grain yield

Source of variation	df	No of flowers	No of pods	Pods with grains	Aborted pods (%)	Aborted pods	Shelling (%)	Harvest index	Pods weight	Grain weight	Biomass yield
Maturity group	1	253ns	83650*	494.4ns	101022**	3939.8ns	47258.14***	1.506***	1074.60ns	886.14*	76533.0***
Error (a)	27	3517	3341	576.5	1818	908.0	45.00	0.0033	149.18	46.76	596.6
Stress period	3	62354***	22586**	5239.4**	7540*	904.2ns	598.52***	0.028***	354.28***	165.44***	1442.7*
MGxSP	3	3352ns	17353**	2678.5*	7174*	900.6ns	329.21***	0.020***	191.22*	75.33*	404.4ns
Error (b)	84	7009	4224	971.4	1891	999.2	54.96	0.0025	59.98	25.54	372.2

*, **, *** denote effects significant at 5, 1and 0.1 percent probability respectively. Ns denotes effects not significant

Table 5: Interactive effects of maturity type and period of moisture stress on yield components of soybean

Maturity group	Stress period	No of flowers	No of pods	Pods with grains	Aborted pods (%)	Aborted pods	Shelling (%)	Harvest index	Pods WT	Biomass
Late	No stress	241.8a	112.8b	70.2a	43.8c	39.2ab	70.4a	0.37a	22.77a	86.7a
	Vegetative	136.3c	89.7b	46.1bc	40.6c	46.8ab	59.4b	0.29b	17.23abc	72.0b
	Flowering	179.9bc	116.2b	63.7ab	49.8bc	44.0ab	58.2b	0.29b	20.68ab	83.3ab
	Pod-filling	182.8bc	100.9b	51.0bc	50.6bc	51.1a	58.7b	0.27b	17.92abc	79.0ab
Early	No stress	235.8a	201.1a	72.6a	128a	34.0ab	28.8c	0.14c	19.77ab	45.7c
	Vegetative	155.3bc	117.2b	43.5c	73.8b	47.1ab	27.4c	0.12c	12.78cd	31.4d
	Flowering	160.7bc	112.6b	37.5c	75.1b	30.5b	22.4d	0.09c	9.14d	30.2d
	Pod-filling	199.2ab	171.8a	63.4ab	108.4a	29.7b	30.6c	0.12c	16.17bc	38.9cd
	s.e.d	24.77	20.01	9.34	13.69	9.88	2.29	0.016	2.868	6.54

Figures followed by te same letter(s) in each column are not significantly different at 5 percent probability level by Duncan's Multiple Range Test

any growth stage reduced the number of pods across maturity groups with significant differences when the stress occurred at both the vegetative and flowering stages. However, significant maturity group by stage of moisture stress interactions revealed that moisture stress at any stage has no significant effects on pod formation in the late maturing type, but significantly reduced pod formation when it occurred at both the vegetative and flowering stages in the early maturity group.

Number of pods with grains were similar for both maturity groupsand was reduced by moisture stress occurring at any growth stage with significant differences when the stress occurred at the vegetative and flowering growth stages. Significant interaction effects showed that number of pods with grains was significantly reduced by stress occurring at the vegetative and pod-filling growth stages in the late maturing type, while the component was significantly decreased by both vegetative and flowering stresses in the early maturity group. Table 5 also shows that pod abortion was lower in the early than in the late maturity group, although the differences were not significant. Pod abortion was increased by moisture stress occurring at any growth stage in the two maturity groups. Both shelling percentage and harvest index were significantly lower in the early than in the late maturing soybean. These two components were reduced

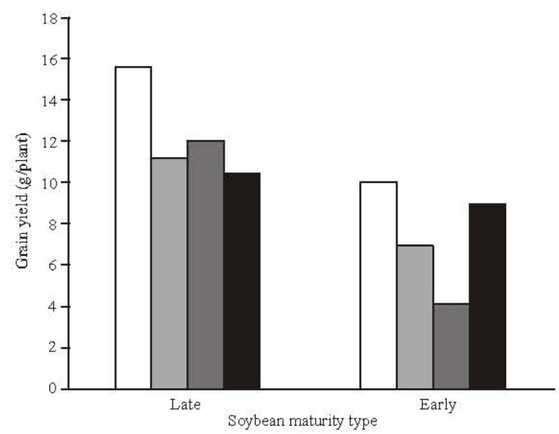

Fig. 4: Interactive effect of maturity type and time of moisture stress on grain yield of soybean

by moisture stress at any growth stage, with significant differences when the stress occurred at the vegetative and flowering growth stages, across soybean types. However, significant interactions showed that moisture stress at any growth stage significantly reduced both the shelling percentage and HI in the late maturity group, while only the stress occurring at flowering significantly reduced shelling percentage in the early maturity group.

Grain yield was significantly lower in the early than in the late maturing type, cross the moisture stress treatments (Fig. 4). The figure also shows that moisture stress at any growth stage reduced grain yield in both maturity groups. However, significant interactions revealed that while stress occurring at the vegetative and pod-filling stages significantly reduced grain yield in the late maturity group, only stress occurring at the flowering stage significantly reduced grain yield in the early maturity group.

DISCUSSION

Results of this study showed that soil moisture stress, especially at the vegetative and flowering growth stages significantly reduced leaf production, branching, plant height and growth indices (CGR and RGR). The reduction in number of leaves may be due to reduction in leaf initiation for the vegetative stress and early senescence which increased leaf shedding with a stress occurring at the flowering stage. It has earlier been reported that soil moisture stress can affect leaf area through its effect in hastening the rate of leaf senescence [17, 18]. Reductions in plant heights in response to soil water stress have been reported for soybean [19], cowpea (*Vigna unguiculata,* (L.) Walp.) [19, 22], wheat (*Triticum aestivum* (L.) [22], grain sorghum (*Sorghum bicolr,* (L.) [23] Similar reduction in branching of cowpea plant subjected to water stress has been reported [24]. Significant interaction effects obtained in this study revealed that moisture stress at any growth stage has no appreciable effects on branching in the early maturing group, while it reduced branching in late maturing group.

Marked reduction in leaf area has been reported to be one of the most important consequences of the sensitivity of cell enlargement to water stress [25] and this may result in decreased photosynthetic activity leading to reduced growth rate and dry matter accumulation as observed in this study. Reduction in growth indices such as NAR, CGR and RGR due to water stress have been reported for soybean [19, 26]. Meckel *et al.* [27] have also reported that severe stress treatments caused large reduction in vegetative plant weight.

Moisture stress was found to reduce most yield components, especially number of pods at harvest, resulting in decreased grain yield. Reduction in grain yield has been reported to be associated primarily with reduction in number of pods and seeds per unit area. [7, 28]. Results of this study show significant positive relationship between grain yield and the number ($r = 0.52^{**}$) and weight ($r = 0.90^{**}$) of harvested pods. Similar positive association between number of pods per plant at harvesting and grain yield has been reported for soybean [3] Floral and pods abortions in soybean are common phenomena which limit yield potentials of the crop [29]. Results of the present study showed that both floral and pods abortions were increased by moisture stress, resulting in significant and negative association ($r = -0.36^{**}$) between percent aborted pods and grain yield. This is also in line with the report of Chiezey [3] who showed a strong negative association between number of harvested pods and pod abortion. These results thereby suggest that inadequate and \ or poorly distributed rainfall in any year can aggravate abortion of reproductive structures and hence reduce yield of the crop as reported by [1, 3, 7]. Therefore the often reported increases in the abortion of the reproductive structures due to high planting densities [30, 31] may be due to competition for moisture.

Mederski and Jeffers [32] and Norworthy [33] have reported that water stress during reproductive development leads to pods shedding and reduced seed size. The floral and pod abortion may be due to poor pollen formation and viability which are considered to be some of the reasons for excessive loss of flowers in legumes, which may be worsened during drought stress. It has been observed that in stressed soybean, flower primordia will not develop nor will anthesis or fertilization be fully effective, resulting in decreased seed yield due to reduced number of seeds [7].

Boyer and Johnson [34] have reported that shortage of water at any stage through the vegetative and flowering phases can lead to reduction in the final yield. Results of this study showed that the reductions in number of harvested pods and grain yield due to moisture stress at any growth stage was dependent on maturity group of soybean. While only stress occurring at flowering stage significantly reduced grain yield in the early maturing group, stress occurring at both vegetative and pod-filling stages significantly reduced grain yield in the late maturity group.

Contrary to the reports of other workers who showed that soybean seed yield is least sensitive to water deficit during the vegetative stage, more sensitive during flowering and most sensitive during pod fill [12] results of this study showed that grain yield was reduced by 19.1, 4.2 and 1.8 percent respectively for vegetative, flowering and pod fill stress across maturity groups.

Nevertheless, significant interaction of maturity group by time of stress revealed that grain yield was reduced by 27.9, 22.3 and 33.6 percent by vegetative, flowering and pod fill stress respectively in late maturity groupand by 31.4, 54.5 and 9.9% for the same stress periods in the early maturity group. These results thereby suggest that late maturity group is most sensitive to a stress at pod fill stage, while early maturing group is most sensitive to a stress occurring at flowering stage.

Across the moisture stress treatments, in this study, results showed that most growth parameters, yield components and consequently grain yield are significantly lower in the early than in the late maturity group. This is in line with the reports of earlier workers which showed that under normal growth conditions, long duration soybeans gave higher seed yield than short duration varieties [35-37]. However, these investigators observed that in adverse years, especially with drought and hot spells of wind during the crop ripening period, early maturing/short duration varieties out yielded their late maturing/long duration counterparts. This is in great contrast with the result of this study which show the superiority of the late maturing varieties at all moisture conditions. It has earlier been observed that earliness or short-season cultivars are usually employed in order to escape drought [25]. However, the results of this study further showed that across stages of stress occurrence, grain yield was reduced by 31.9% in the early maturity groupand by 27.9 % in the late maturity group, thereby in support of Turner and Rawson [38] who observed that the benefit of early maturity as a means of escaping drought can be questionable.

In conclusion, results of this study showed that soil moisture stress occurring at any growth stage can be detrimental to grain yield in soybean depending on the maturity group, while early maturing soybeans are mostly adversely affected by a stress occurring at the flowering stage, pod filling stress is most critical for the late maturing varieties.

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