QUANTIFYING THE EFFECT OF DIFFERENT SOWING DATES ON THE PRODUCTIVITY OF TWO ELITE SOYBEAN GENOTYPES PRODUCTIVITY IN THE FACE OF CLIMATE CHANGE

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Abstract

Rainfall in Sub-Saharan Africa (SSA) would decrease by about 20%, making some agricultural land in SSA unsuitable for cultivation, resulting in yield losses. The extent of these yield losses is unclear, but some analysts predict they could be severe. Increasing climate variability could lead to declining soil moisture, increasing drought, salinization and groundwater depletion. Soybean is a thermophilic and photophilic crop and is therefore sensitive to seasonal weather patterns. Planting date is an agronomic measure to manage climatic impacts. It affects stand establishment, physiological parameters, and yield formation. We investigated the effects of five sowing dates on two improved soybean genotypes (Gyidie & Tundana) during the 2021 and 2022 cropping seasons. A 2 x 5 factorial design with five replications was used for this study. The genotypes, Gyidie & Tundana, were the first factor while sowing date was the second factor. Sowing commenced on the 1st of June in 2021 and on the 5th of April in 2022. The sowing dates tested were day 1 (1st June and 5th April, respectively), 5 days later, 10 days later, 15 days later, and 20 days later. The results showed significant ($p \leq 0.05$) vegetative and yield differences effects among genotypes. The genotype *Tundana* yielded 11.2% and 6.5% higher grain yields than *Gyidie* in both years. Day to maturity was shortened by 1 to 11 days as sowing days were delayed from 5 to 20 days. Rainwater harvesting efficiency was significantly higher in the early-sown crops, which had a significant ($r = 0.99$) effect on grain yield. Grain yield decreased by 5.1 - 6.7% after 5 days delay, 14.8 - 19.3% after 10 days delay, 22.8 - 24.3% after 15 days delay, and 28.4 - 29.3% after 20 days delay in 2021 and 2022. Grain quality (oil and protein content) was not affected by late sowing. The results suggest that farmers have a better chance of higher yields if they sow these genotypes early to take advantage of the early rains. In the worst-case scenario, farmers should not delay the sowing date of soybean more than 5 days to minimize yield losses.

Keywords: Climate change, Sowing date, Rainwater use, Growth phenology, Yield, Soybean

Introduction

Soybean (*Glycine max* L.) is a useful legume that is cultivated in both developed and developing countries (Omondi *et al*., 2023). Soybean production is relatively new in Ghana (Dogbe *et al*., 2013), but its economic relevance is growing among farmers (Etwire *et al*., 2013). Soybean is an important crop for the Ghanaian economy, particularly for oil and protein production. Soybean contains 18-25% oil and 40-44% crude protein on average (Yilmaz, 2003). It is an important cash crop to the Ghanaian economy mainly for oil production and as a source of protein. On average, soybean contains 18-25% oil and 40-44% crude protein (Yilmaz, 2003). Despite the importance of this crop, Ghana's soybean yield (only about 1.3 t/ha, Mahama *et al*., 2020) and productivity per hectare are lower than in major producing countries such as the United States, Brazil, and China though soybean output potential in Ghana is projected to be 2.8 t/ha. As a result, there is a huge gap between Ghana's soybean consumption and total production, which leads to huge imports from Brazil and the USA (Lambon *et al*., 2018). Ghana can increase its soybean production and reduce importation and even become a net exporter of soybean to neighbouring countries if small-scale and commercial farmers improve their farm productivity by adopting to improved agronomic practices (Mbanya, 2011; Shegro *et al*., 2010). Though the development of high-yielding varieties has remarkably contributed to raising yields, there is a need for timely good agronomic practices (GAP) to stabilize these higher yields (Shegro *et al*., 2010; Acosta-Gallegos *et al*., 1996; Olufajo and Pal, 1991), especially in this era of climate change. Climate change and food security have an immutable link. Africa is already and will continue to suffer the downstream effects of climate change, therefore, underlining a need to have climate-adaptive food systems. There is a need to quantify yield loss gaps that may occur when GAP is delayed. SSA would experience decreased rainfall by about 20% (Parry *et al*., 2007). Thus, some agricultural lands in SSA may become unsuitable for cropping (Bals *et al*., 2008), leading to crop yield reduction. The extent of these declines in yields is unclear, however, some analysts predict it could be severe (Bals *et al*., 2008). This increase in temperature plus reduced rainfall can lead to the loss of arable land due to decreased soil moisture, increased aridity, increased salinity and groundwater depletion (Bals *et al*., 2008). Optimization of sowing dates is an important and non-monetary agronomic practice that influences soybean yield (Shegro *et al*., 2010; Robinson *et al*., 2009). Chen & Wiatrak, (2010) reported that mid-June planting increased seed yield by 26% and 55% over early July and late July in the USA. Salmerón *et al*. (2015) also reported similar trends in the USA. Delaying the sowing date by 20 days in relation to the earliest (16–21.04) resulted in the shortening of the length of the vegetative development by 12 days and the shortening of the entire vegetation period by 14 days. The delayed sowing date (06–19.05) under the conditions of southwestern Poland contributed to a significant decrease in yield (Serafin-Andrzejewska *et al*., 2021). This makes information on timely sowing dates for crops very important to resource-poor smallholder farmers in developing countries since many cannot afford supplemental irrigation.

Photoperiodism, temperature, and precipitation amount and duration change with sowing date, affecting the length of vegetative and reproductive growth phases of soybean, and hence the yield (Serafin-Andrzejewska *et al*., 2021; Bastidas *et al*., 2008; Board

& Harville, 1996). Temperature and photoperiodism interact to initiate flowering. Soybean is a thermophilic and photophilic sensitive plant, therefore if such conditions are poor, flowering may be too early (causing less dry matter accumulation). Sowing date also significantly influences seed viability, the environmental conditions prevalent during the ripening and harvesting stages are a very important determinant of viability (Kundu *et al*., 2016). Under changing climate and unpredictable drought, uncertainties in yield are common and require an adjustment of sowing date to control yield lapses. Drought stress during the reproductive stages reduces carbon dioxide exchange rate, photosynthesis, sugar production, and the flow of metabolites to expanding cells which intend decreases vegetative growth, increases flower and pod abortion, decreases duration of seed filling phase, seed number, and seed size (Mengxuan & Wiatrak, 2012). Most recent studies on the impact of drought on soybean productivity are mainly focused on above-ground traits (Mourtzinis *et al*., 2019). Root nodules are important sensors of drought, the responses of this crucial organ and its drought tolerance features remain poorly characterized. There are less investigations on the impact of sowing date on soybean yield and root nodule mass in Ghana, even though improved varieties are released periodically by the CSIR-Crops Research Institute and the Savanna Agriculture Research Institute of Ghana. Therefore, this study tested the hypotheses that soybean growth phenology, yield reduction, and nodule mass can be explained by the sowing date.

Experimental

Research location

The field trial was conducted at the experimental farms of CSIR-Crops Research Institute, Fumesua, Ghana, located at latitude. 5° 3' 18" north and longitude 2° 29' 18" west, at an elevation of 285m. The mean rainfall from June to October 2021 and April to August 2022 were 253.8 mm and 136.6 mm, respectively. Average monthly maximum temperatures were 23.12 ^{0}C and 23.08 ^{0}C, respectively. Relative humidity during the growing period was 94.76% in 2021 and 90.14% in 2022. The mean evaporation during the crop growth period was 4.38 mm per week. The monthly average meteorological conditions at the research site are shown in Figure 1.

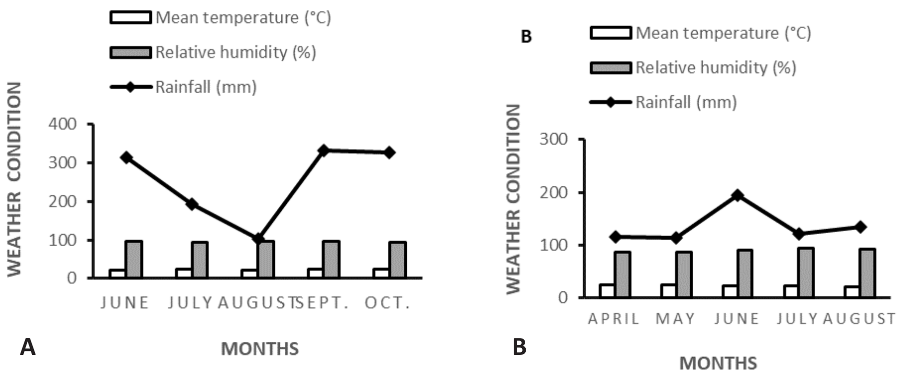

Fig. 1: Weather conditions during the crop growth period 2021 (A) and 2022 (B). Source: CSIR: Crops Research Institute, Kumasi-Ghana.

The soil at the research field was Ultisols (WRB) and sandy clay textured. Before the trial in 2021, five soil samples were diagonally collected from a depth of 10-20 cm. Sampling was done with an AMS soil sampler (AMS, Inc., American Falls, Idaho). A composite of 500 g was taken to the laboratory for physicochemical properties analysis (Table 1). Pan *et al*. (2012) methods were followed for the physical properties' determination, while the routine methods of A.O.A.C. (1976) were followed for the chemical properties' estimation. Total nitrogen was determined by the Kjeldahl analysis, while the determination of other nutrient element concentrations was done by the inductively coupled plasma emission spectrometry 4300 Optima DV (PerkinElmer Instruments, Norwalk, CT). The organic carbon analysis followed the potassium dichromate oxidation method, while soil reaction (pH) was recorded in a 1:1 water solution ratio with an electrode (H19017 Microprocessor) pH meter. Electrical conductivity (EC) was measured with an EC meter. Soil water content during the crop growth duration was measured gravimetrically from 10-15 cm soil depth with a moisture tester (Takemura Electric Works-Model DM-15).

TABLE 1

Physical and chemical properties of soil of the experimental field.

Physical properties	Coarse sand %	Find sand %	Silt %	Clay %	Textural class	
	7.58	19.33	26.57	52.25	Sandy clay	
Chemical properties	N kg/ha	P kg/ha	K kg/ha	Organic carbon %	Soil reaction (pH 1:1)	EC (dS/m)
	150.53	21.15	574	0.52	6.20	0.21

N: nitrogen; P: phosphorus; K: potassium and EC: electrical conductivity

Experimental materials

Two improved soybean genotypes: *Gyidie* and *Tundana* were sourced from the Legumes and Oilseeds Division of CSIR-Crops Research Institute, Ghana. Nitrogen inoculant (*Rhizobium japonicum*) was sourced from the Kwame Nkrumah University for Science and Technology, while urea, diammonium phosphate, muriate of potash fertilizers and chlorpyriphos 20 EC were sourced from AGRIMAT LTD.

Experimental details

The trial used a 2 × 5 factorial setup in Randomized Complete Block Design with 4 replications in a plot sizes of 5 m × 4.5 m. The treatment structure comprised two soybean genotypes and five sowing dates: day 1, 5 days late, 10 days late, 15 days late and 20 days late. In 2021, sowing commenced on 1st June while the 2022 sowing began on 5th April. Before sowing, the seeds were treated with *Rhizobium japonicum* (Freitas *et al*., 2016), at a rate of 30 g/kg of seeds. Seeds were sown by the dibbling method at 45 cm between rows and 5 cm within rows. Based on the soil analysis results, a recommended fertilizer dose of 30 kg N_2, 60 kg P_2O_5, and 30 kg K_2O was applied per ha in two splits; 50% was applied at 14 days and 30 days after sowing (DAS), at 5 cm distance and depth from the plants. Hoeing was carried out when needed to control weeds and one spray of chlorpyriphos 20 EC was applied to control leaf-eating caterpillars. The trial was rain-fed and no irrigation was given.

Growth and yield data

Days taken to 50% flowering of the entire plot per treatment were counted. Ten plants in the middle rows were randomly sampled per plot and tagged for periodic data measurement. Parameters measured were: plant height, leaf area, leaf chlorophyll, and total dry matter. Measurement of plant height, leaf area and leaf chlorophyll were done at the flowering stage, while the total dry matter accumulated was estimated after harvest. Plant height was measured from the base of the plant to the tip of the shoot apex. The SPAD-502 chlorophyll meter (Minolta Camera Co., Ramsey, NJ) was used to measure leaf chlorophyll (surrogate) content from ten sampled apical leaves per plant. At harvest, the above-ground biomass of 5 sampled plants were oven-dried at 70 ± 2 ºC for 12 hrs, Their weight were taken and the average worked out as total dry matter measurement. Fresh root nodules were detached from the 10 sampled plants and weighed. A handheld laser leaf area meter (SYSTRONICS, Leaf Area Meter-211) was used to measure leaf area at 60 DAS. Leaf area plant^{-1} and leaf area index (LAI) were afterwards calculated with Pawar (1978) and Fisher (1921) formulas in equations 1 and 2, respectively.

$$\text{Leaf area/plant (cm}^2\text{)} = \sum_{i=0}^{n}(L \times D)K \quad (1)$$

Where; L, D, n, and K are leaf length, leaf diameter, number of leaves, and leaf area constant for soybean (0.689), respectively.

$$\text{LAI} = \frac{\text{Leaf area/plant(cm}^2\text{)}}{\text{Ground area/plant (cm}^2\text{)}} \quad (2)$$

The number of days taken to harvest at physiological maturity was counted. The number of seeds plants^{-1} was counted from the 10 sampled plants. The harvested pods plot^{-1} were threshed with a mechanic threshing machine and the seeds were dried to 13% moisture content, moisture measurement was done by the moisture meter (FARMEX model, Delhi, India). Seed yield plot^{-1} was recorded and converted into ha by the formula in equation 3.

Where mc is the moisture content taken at harvest, 87 is adjusted moisture content.

$$\text{Grain yield (kg ha}^{-1}\text{)} = \text{grain weight (kg plot}^{-1}\text{)} \times \left(\frac{100 - \text{mc}}{87}\right) \times \textit{plant population ha}^{-1} \quad (3)$$

The seed yield and straw yield were summed and recorded as biological yield (total biomass). Harvest index (HI) was determined as the amount of biomass allocated to the vegetative apparatus versus the reproductive organ. HI was calculated by equation 4.

Dry matter use efficiency (DMUE) and rainwater use efficiency (RWUE) were worked out as in equations 5 and 6. The average effective rainfall for 2021 and 2022 were 317.5 and 368.6 mm, respectively. Sixty (60 g) of seeds were sampled from each replication for grain quality assessment (oil and protein content). The micro Kjeldahl method of A.O.A.C. (1976) was followed to estimate seed oil and protein content. Percent of crude protein was calculated with a multiplying factor of 6.25. Oil content was estimated by Soxhlet ether extraction. All laboratory

$$\text{HI \%} = \frac{\textit{Seed yield (kg)}}{\textit{Biological yield (kg)}} \times 100 \quad (4)$$

works were conducted at the Bio-chemistry laboratory, CSIR-Crops Research Institute.

$$\text{DMUE } (\%\ \text{day}^{-1}) = \frac{\text{Grain weight /plant (g)}}{\text{Total dry matter/plant (g)}} \times \frac{100\ (\%)}{\text{Duration of crop (days)}} \quad (5)$$

$$\text{RWUE } (\text{kg ha}^{-1}\ \text{mm}^{-1}) = \frac{Yield\ kg/ha}{Moisture\ use(effective\ rainfall)\ mm} \quad (6)$$

Statistical analysis

Data collected was analyzed by Fisher's method of Analysis of Variance (ANOVA) using SPSS 21 statistical package. Statistically significant treatment means were separated with Fisher's least significant difference (LSD) at $p \leq 0.05$. Tukey's Honestly Significant Difference (HSD) test was used for mean separation. Correlation analysis was performed to show the relation between variables.

Results and Discussion

Growth

Soybean is a thermophilic and photophilic plant, so very sensitive to weather courses during the vegetative phase. The results in Table 2 depict the effect of genotype and sowing date on vegetative and physiological growth. Plant height varied significantly ($p \leq 0.05$) between genotypes in 2021 but not in 2022. The genotype, *Tundana* grew taller than *Gyidie* in both years. In 2021, sowing date did not affect plant height but it caused a significant ($p \leq 0.05$) increase in 2022. A decreasing trend in height was observed as the sowing date was delayed. Early sowing produced the tallest plant (68.65 cm) in 2022 but was comparable to 5, 10 and 15 days late sowing. Plant height was generally higher in 2022 among the genotypes and sowing dates compared to 2021. The interaction between genotype and sowing date had no significant effect on height. LAI was significantly ($p \leq 0.01$) influenced by genotype and sowing date in 2021, and by sowing date in 2022. Genotype and sowing date interacted significantly ($p \leq 0.01$) to affect LAI. The genotype, *Tundana* produced a broader leaf area compared to *Gyidie* in 2021 but the reverse occurred in 2022. Early sowing produced larger LAI in both years. The LAI decreased progressively by 6.5% – 21.3% in 2021, and by 2.9% – 23.9% in 2022 for every 5 days delay in sowing from day 1 to 20. The dry matter accumulated by the genotypes was not significantly different. Sowing on day 1 accumulated the highest dry matter in 2021 (43.97 g) and 2022 (50.20 g). The amount of matter accumulated decreased with every 5 days delay in sowing. A decrease of 6.6%, 12.05%, 26.3%, 28.7% and 9.20%, 15.7%, 24.4%, 32.2% were recorded in 2021 and 2022. However, this could not lead to a significant DMUE among the sowing dates but that of the genotypes differed. Further, *Tundana* had a higher dry matter accumulation rate (0.23% day^{-1} and 0.25% day^{-1}) than *Gyidie* in 2021 and 2022, respectively. Genotype and sowing dates interacted significantly ($p \leq 0.05$) to affect DMUE. Leaf greenness (surrogate chlorophyll) content was also affected ($p \leq 0.01$) by genotype in 2021 and by sowing dates in both years. Consistent with the other measured variables, *Tundana* contained more chlorophyll than *Gyidie* while sowing on day 1 similarly, contained the highest chlorophyll. Leaf chlorophyll content declined as sowing date was delayed. The differences observed between the genotypes vegetative growth could be attributed to genetic variation. The *Tundana* cultivar is generally taller with broad leaves. The higher vegetative apparatus accrued by *Tundana* resulted in the higher dry matter it produced. The larger the LAI, the more avail is the leaf surface area to incept active solar radiation for photosynthesis (Keteku *et al*., 2021; Soltani & Sinclair, 2012; Steduto *et al*., 2009). The LAI and dry matter are yield indicators, therefore a genotype that produces greater of these has a higher potential to yield (Keteku *et al*., 2021; Kadam et 2020). Although the degree and trend varied with genotype, such findings are not unusual and have been reported by (Sobko *et al*., 2019; Kandil *et al*., 2013). The amount of rainfall received during the vegetative period (Figure 1) could explain the performance between the sowing dates and also, the years. In 2021, rainfall amount reduced sharply from June to August, a phenomenon that can cause a reduction in the vegetative apparatus gathered by the late-sown plants. This argument is supported by Figure 3, soil moisture content and RWUE were equally reduced as the sowing date was delayed. Water is the main soil solvent that supplies nutrients to plants' roots and microbes, therefore, a lack of it limits nutrient availability to these entities (Bista *et al*., 2017; Kandil *et al*., 2013). A reduction in leaf nitrogen will affect leaf chlorophyll content (Nematpour *et al*., 2020; Gholamin & Khatnezhad, 2011). This shows a clear pattern of competitive advantage (water and nutrient availability) to early sown plants. When soil moisture is less, crops show little to no responses to applied fertilizer limiting their ability to build biomass. Under such conditions, plants' adaption mechanisms are stimulated and dry matter accumulation is hastened (Kumagai & Takahashi, 2020; Brevedan & Egli, 2003), to enable early maturity (Figure 2D). Though the process became rapid, the naturally expected vegetative growth duration was reduced (Figure 2), hence the total dry matter accumulated was less. A reduction in leaf area due to late sowing can be attributed to less water (Quan *et al*., 2016). Berchie *et al*. (2012) and Vurayai *et al*. (2011) reported of a decrease in leaf area development in response to water shortage. In this study, the results of leaf area index provided an important clue to the physiological role of the leaf in possibly improving plant performance. Days taken to 50% flowering decreased by about 1-8 days from 5 to 20 days delay in 2021 and about 1-5 days in 2022. Similarly, days to maturity were earliest in the late sown plants, an approximately 12 days earliest in the 20 days delayed sown plants in both years (Figure 2). Consistent with this study, Salmerón *et al*. (2015) reported that delaying the sowing date by 20 days in relation to the earliest resulted in the shortening of the length of the vegetative development by 12 days and the shortening of the entire vegetation period by 14 days in the USA. This can imply a huge loss of time needed to gather yield. The *Rhizobium japonicum* treatment was aimed to improve nitrogen fixation and availability to crops. According to Delves *et al*. (1986), after Rhizobium bacteria invade legume roots, the formation of N-fixing nodules is dependent on internal and external factors available to the host plant. The progressive decline in root nodule weight observed in the study (Table 3) confirms that internal and external factors had an impact. As genotype and sowing date changed, root nodule weight changed. Genotype differences can be related to genetics while that of sowing can be attributed to the climate vagaries. This outcome could have affected the plants vegetative growth performance through a decrease in plant nitrogen as shown by leaf chlorophyll content.

TABLE 2

Influence of genotype and sowing date on growth phenology

Treatments	Plant height (cm)		LAI		Dry matter (g)		DMUE (% day^{-1})		Chlorophyll (SPAD)	
Genotypes	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Tundana	66.80^{a}	67.20	6.24^{a}	6.30	38.02	40.99	0.23^{a}	0.25^{a}	84.13^{a}	75.63
Gyidie	60.71^{b}	66.12	5.66^{b}	6.42	37.19	43.05	0.21^{b}	0.20^{b}	79.78^{b}	71.68
Lsd (0.05)	5.47	ns	0.24	ns	ns	ns	0.02	0.02	2.15	ns
Sowing dates										
Day 1	64.03	68.65^{a}	6.74^{a}	7.28^{a}	43.97^{a}	50.20^{a}	0.22	0.22	90.47^{a}	82.28^{a}
5 days late	63.14	67.22^{a}	6.30^{b}	7.07^{a}	41.17^{ab}	45.58^{b}	0.22	0.25	85.18^{b}	79.34^{a}
10 days late	63.78	66.95^{a}	5.89^{c}	6.13^{b}	38.67^{b}	42.33^{b}	0.20	0.21	84.66^{b}	77.56^{a}
15 days late	63.56	66.43^{ab}	5.53^{cd}	5.78^{bc}	32.86^{c}	37.93^{c}	0.24	0.23	76.16^{c}	66.77^{b}
20 days late	64.28	64.05^{b}	5.31^{d}	5.54^{c}	31.37^{c}	34.03^{d}	0.24	0.23	73.30^{c}	62.33^{b}
Lsd (0.05)	ns	2.58	0.38	0.49	4.64	3.85	ns	ns	3.40	8.44
Interaction	ns	ns	**	ns	ns	ns	ns	*	ns	ns

*Note: mean values with a different superscript letter within each column denotes significance between different groups (n = 4). **; * = significant at 1% and 5% probability levels, respectively. ns = non-significant. Lsd = least significant difference.*

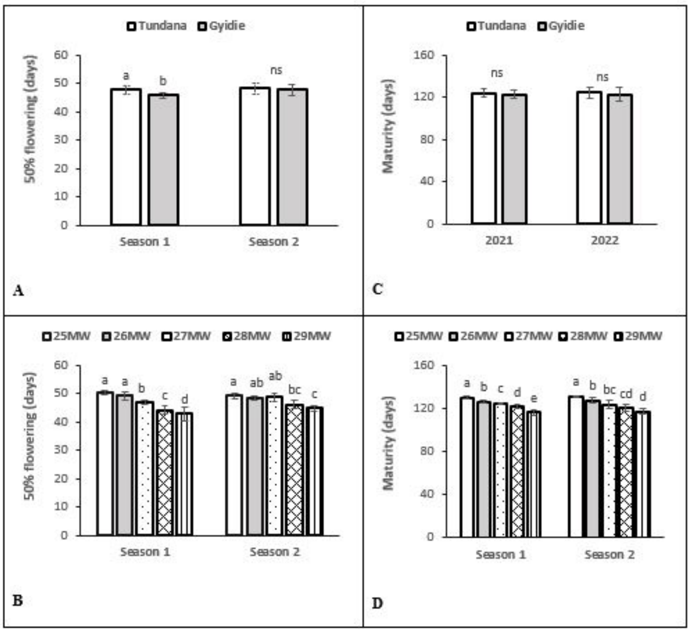

Fig. 2: Influence of genotype and sowing date on days to flowering (a, b) and days to maturity (c, d). Note: mean values with a different alphabets letter on the bar denotes significance difference (n = 4). **; * = significant at 1% and 5% probability levels. ns = non-significant.

Yield

The effect of genotype and sowing date was significant ($p \leq 0.01$) on the number of seeds plant^{-1} except between genotypes in 2021 (Table 3). *Tundana* produced about 8 more seeds compared to *Gyidie*. The number of seeds decreased per plant as the sowing date was delayed. Early sowing had the highest number of 107.47 and 113.72 seeds in 2021 and 2022, respectively but was comparable to sowing 5 days late. The number of seeds decreased by approximately 1-11 seeds for every 5 days delay in the sowing date. This cumulatively affected the seed yield produced per hectare. Genotype and sowing date significantly affected seed yield. Additionally, *Tundana* had 11.2% and 6.5% higher grain yield in 2021 and 2022, respectively than *Gyidie*. The decline in grain yield among the sowing dates was more severe in 2021 than in 2022. The decline was 6.7% after 5 days delay, 19.3% after 10 days delay, 24.3% after 15 days delay and 29.3% after 20 days delay in 2021 (Figure 4). In 2022, it decreased by 5.1% after 5 days delay, 14.8% after 10 days delay, 22.8% after 15 days delay and 28.4% after 20 days delay. The decrease was highly significant ($p \leq 0.01$) in both years. This decrease in grain yield correspondingly led to a low HI (Table 3). HI for soybean should not be less than 20 (Liu *et al*., 2019). The HI provides insight into how practical agronomic management and genetics determine crop yield potential. An HI of 36.91 and 39.15 were recorded when plants were sown early (day 1) in 2021 and 2022, respectively but it was at par with sowing 5 days late. From these, it decreased to 30.04 and 33.16 after 20 days of delay in 2021 and 2022, respectively. Grain yield and HI in 2022 were generally higher compared with 2021 even though the rainfall received in 2021 was higher. The differences observed in the grain yield may be attributed to the vegetative performance of the treatments, translated to yield component and yield. The significant correlation ($r = 0.96$; 0.94) of days to flowering and maturity (Table 4A) implies that treatments that flowered early also matured earlier. In other words, these plants had a shorter growth duration to express their full yielding potential (Brevedan & Egli, 2003). As a result, days to flowering and maturity significantly ($r = 0.98$ and 0.91) correlated to grain yield in 2021, respectively and by ($r = 0.92$ and 0.99) in 2022, respectively. The impact of days to flowering and maturity on yield is further explained by the correlation of RWUE ($r = 0.99$) to grain yield (Table 4B). Efficient utilization of rainwater played a major role in yield differentiation in this study. A similar finding has been reported by (Nematpour *et al*., 2020). The slightly sharp decline in rainfall from June to August (Figure 1A) may have coincided with the seed filling stage of the crop and affected yield in 2021. Though some late sown plants may have escaped this period and had their podding and seed filling phase after August, the less vegetative apparatus gathered before podding could affect water utilization. The reverse was observed in 2022 (Figure 1B), rainfall peaked at podding and seed filling stage (June) to benefit yield, hence the higher yields observed in 2022. Seed number is dependent on assimilates supplied before the seed-filling stage (Van Roekel *et al*., 2015). De Bruin and Pedersen, (2008) mentioned that the impact of late planting on yield was due to the reduction in the number of seeds m^{-2}, an observation made in this current study as well. In addition, the high yield in 2022 could also be due to the nutrient residues from 2021, owing to the aftermath of fertilization, nitrogen fixation and R. japonicum inoculation (Keteku *et al*., 2022; Zhang *et al*., 2022). This result confirms previous findings from other countries. Liu *et al*. (2021) reported that grain yield declined by 0.97 ± 0.22% with each one-day change (either early or delayed) in sowing beyond the normal sowing date. The study explained that yield loss could be explained by the inhibition of crop growth, yield components, biomass and nitrogen (N) production. The negative effects of delayed sowing were caused by environmental limitations including adverse weather factors such as low temperature during vegetative growth, shortened duration of various phases of crop development, and increased temperature during the grain-filling period. The grain yield gap decreased between the late and normal sowing periods owing to a compensatory effect between the highest average rates and the rapid accumulation period of dry matter. Also, Zhang *et al*. (2022) found that sowing on April 1st resulted in higher grain yield while sowing on May 1st reduced the yield. Similarly, Serafin-Andrzejewska *et al*. (2021) stated a significant decrease in seed yield after delaying sowing for 6 –19.05 days in Poland. Chen & Wiatrak, (2010) observed that mid-June planting increased seed yield by 26% and 55% over early July and late July sowing in the USA. Kumagai & Takahashi, (2020) also reported a 44% yield reduction in soybean due to delayed seeding. The grain yield loss recorded in this present study in both years are within this rsniange.

TABLE 3

Influence of variety and sowing date on soybean yield

Treatments	Fresh nodule weight (g)		Seeds plant^{-1}		Yield ha^{-1} (Kg)		HI	
Genotypes	2021	2022	2021	2022	2021	2022	2021	2022
Tundana	94.11	95.06^{a}	100.49	102.55^{a}	1966.18^{a}	2019.57^{a}	35.07^{a}	37.76^{a}
Gyidie	99.83	82.91^{b}	94.77	94.17^{b}	1746.32^{b}	1889.11^{b}	30.88^{b}	35.20^{b}
Lsd (0.05)	ns	9.24	ns	5.47	75.45	118.83	1.39	2.14
Sowing dates								
Day 1	104.33^{a}	103.80^{a}	107.47^{a}	113.72^{a}	2208.03^{a}	2278.72^{a}	36.91^{a}	39.15^{a}
5 days late	100.58^{ab}	100.82^{a}	100.73^{ab}	109.47^{a}	2060.50^{b}	2161.52^{a}	35.54^{a}	38.17^{ab}
10 days late	97.75^{abc}	90.08^{ab}	101.65^{ab}	98.48^{b}	1781.48^{c}	1942.53^{b}	31.90^{b}	37.03^{ab}
15 days late	94.02^{bc}	76.62^{bc}	94.77^{b}	89.68^{c}	1670.47^{cd}	1758.12^{bc}	30.46^{b}	34.88^{bc}
20 days late	88.17^{c}	73.62^{c}	83.54^{c}	80.43^{d}	1560.77^{d}	1630.80^{c}	30.04^{b}	33.16^{c}
Lsd (0.05)	10.29	14.60	10.22	8.65	119.30	187.89	2.19	3.39
Interaction	ns	ns	ns	ns	**	ns	ns	ns

Note: mean values with a different superscript letter within each column denotes significance between different groups (n = 4). **; * = significant at 1% and 5% probability levels, respectively. ns = non-significant. Lsd = least significant difference.

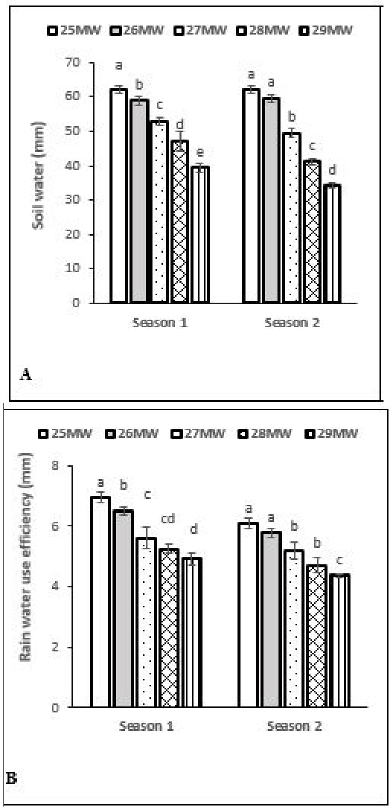

Figure 3. Influence of variety and sowing date on soil water content after harvest (a) and rain water use efficiency (b). Note: mean values with a different alphabets letter on bar denotes significance difference (n = 4). *; ** = significant at 0.01 and 0.05, respectively.

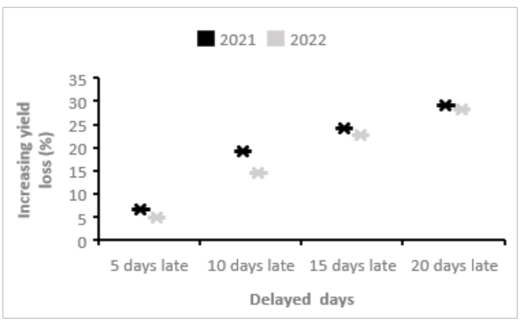

Fig. 4: Percentage grain yield loss caused by late sowing in soybean

TABLE 4

Correlation coefficient (r) of day to 50% flowering, days to maturity, rainwater use efficiency and dry matter use efficiency to grain yield

Years	Years
Grain yield (Kg	Grain yield (Kg ha^{-1})
ha^{-1})	RWUE
DF	
	2021
2021	RWUE
DF	0.99**
0.98**	0
0	
	DMUE
DM	-0.45ns
0.91*	-0.45ns
0.96**	
	2022
	RWUE
2022	0.99**
DF	0
0.92*	
0	
	DMUE
	0.07ns
DM	-0.45ns
0.99**	
0.94*	B
A	

Note: DF = Days to flowering; DM = Days to maturity; RWUE = Rain water use efficiency; DMUE = Dry matter use efficiency; ** = Significant at 1% probability level; * = Significant at 5% probability level; ns = non-significant

Grain quality was not significantly affected by genotype or sowing date but slightly higher protein content was observed in the early sown dates (Figure 5). Sowing on day 1 and 5 days late recorded the highest oil and protein contents in 2021 and 2022 with the lowest recorded in seeds sown 20 days later. High temperatures during the reproductive phase enhanced oil content (Mengxuan & Wiatrak, (2012). The relatively stable temperature across all the sowing dates (Figure 1) may have resulted in the stable oil content in the grains. Previous research works have provided much information of the impact climatic stress imposes on nodulated plants like soybean. Pfeiffer *et al*. (1983) reported a rapid attenuation of nitrogenase activity which led to a decrease in total nodule protein due to changes in climate vagaries. This can lead to a significant decline in seed protein content but this wasn't the case in this present study. Though a slight decrease was observed, it wasn't significant. The present result confirms Tsein *et al*. (1977) and Tu, (1975) finding that bacteroids are stable in determinate nodules such as in soybean, even during stress period. Sobko *et al*. (2019) found that the environment was the dominant factor affecting protein content rather than genetics. This could be the reason why no significant variation in protein content was observed between the genotypes.

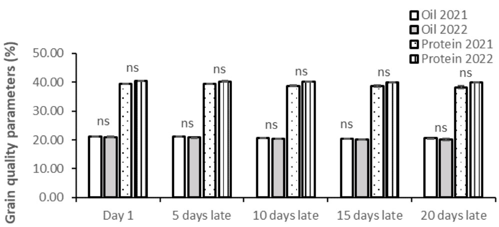

Fig. 5: Effect of variety and sowing date on grain quality parameters. ns = non-significant

Conclusion

Results of this study showed that sowing date significantly affected rainwater use efficiency, days to 50% flowering, dry matter accumulation, leaf area index, days to maturity and yield. Genotypic differences were much more pronounced in the vegetative and yield indices. Crop growth phases like flowering and maturity were shortened when sowing date was delayed and this leads to significant yield losses. The days to flowering significantly affected the days to maturity and both phases significantly correlated to grain yield. Early sown plants maximized rainwater while those sown late had a low rainwater use efficiency. An average yield loss of 5 - 29% occurred when sowing date was delayed from 5 days to 20 days. The effect of sowing date on the rate of dry matter accumulation did not affect grain yield. Grain quality parameters (oil and protein) contents were not compromised when sowing date was delayed. The finding implies that farmers stand a better chance of higher yield if they take advantage of the early rains. At worst, farmers should not delay soybean sowing date for more than 5 days to minimize yield losses.

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