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Plant density and variety effect on yield, leaf spot disease, weed species richness and diversity of groundnut production in northern Ghana

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Abstract

Low plant density and weed infestation are major challenges for groundnut production in northern Ghana. A two-year on-farm study was conducted to determine the effect of plant density and variety on grain and fodder yields, incidence of leaf spot disease, weed species diversity and biomass. A factorial treatment combination of 6 varieties and 4 plant densities laid in strip plot design with 4 replications was used. The varieties were (early maturity type: Chinese, Yenyewoso, Samnut 23 and late maturity type: Azivivi, Manipinta, Samnut 22). The plants density included 9, 11, 15 and 22 plants/m^2. The late maturity varieties recorded higher ($p < .05$) canopy cover, grain and fodder yields relative to that of the early maturity varieties. The late maturity varieties also recorded the least sedge weed species frequency, density and incidence of leaf spot disease compared with that of the early maturity varieties. The canopy cover, grain and fodder yields increased with increasing plant density. Broadleaf weed species frequency and density, weed biomass, richness, and diversity declined with increasing plant density. Grain yield showed negative and significant correlation with broadleaf weed species frequency, density and weed biomass. The results suggest that both early and late maturity groundnut varieties can be planted at a density of 22 plants/m^2 to increase grain and fodder yields and reduce weed species richness, diversity and growth in northern Ghana and similar agro-ecology in West Africa.

KEYWORDS

Arachis hypogaea, crop density, grain and fodder, savanna, weed

1 | INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is among important grain legume crops in the world especially in the tropic and sub-tropic regions due to its adaptation to the climatic conditions and limited diseases (Prasad et al., 2009). The grains are good source of protein, as well as vitamins and the fodder is also a source of quality feed for livestock (Abdul Rahman, Ansah, et al., 2019; Ansah et al., 2021; Larbi et al., 1999). It provides food for household consumption, generates household income, and plays an important role in amelioration of soil fertility through biological nitrogen fixation (Jolly et al., 2008; Sanginga, 2003).

In Ghana groundnut is predominantly produced in the northern savanna as a cash crop with about 90% of farm households involved in its cultivation (Tsigbey et al., 2003). It is cultivated on subsistence basis under rainfed on an average plot size of 0.6–1.3 ha (Amanor-Boadu et al., 2015; Tsigbey et al., 2003). The average pod yield of groundnut is 1.7 t/ha compared with a potential yield of 3.5 t/ha (MoFA, 2021). This yield gap is caused by several factors and key among them are low plant density, disease infection and weed infestation. Typical plant density on farmers' fields is less than 10 plants/m^2 in northern Ghana (Naab, Boote, et al., 2009). Although several on-station studies have shown that an increase in plant density corresponds to an increase in grain and fodder yields of groundnut (Bakal et al., 2020; Dapaah et al., 2014; Naab, Seini, et al., 2009). However, the adoption of plants density above 10 plants/m^2 among smallholder farmers especially in northern Ghana is still low. One of the key reasons for the low adoption of high plant density among smallholder farmers could be inadequate knowledge about the technology as there is little or no participation of farmers in developing the technology which in turn affects their capacity and confidence to apply the technology. Groundnut is also prone to attack by many fungal foliar diseases and key among them is the Cecospora leaf spot disease (early leaf spot disease: *Cercospora arachidicola* and late leaf spot disease: *Cercosporidium personatum*) which contributes to more than 50% yield loss if not controlled (Kankam et al., 2022; Kokalis-Burelle et al., 1997; Kumar & Thirumalaisamy, 2016; Tsigbey et al., 2003). Weed infestation is another challenge for smallholder groundnut farmers in northern Ghana and it is reported to cause a yield loss of about 70%–90% in groundnut production worldwide (Agostinho et al., 2006; Everman et al., 2008). Broadleaf weed species are the common weeds in groundnut fields in northern Ghana and key among them are *Commelina benghalensis* L. (Tropical spiderwort), *Mitracarpus villosus* (Sw.) DC. (Tropical girdlepod), *Hyptis suaveolens* Poit. (Pignut), *Vernonia galamensis* (Cass.) Less. (Ironweed) (Dzomeku et al., 2009). In northern Ghana most of the smallholder farmers do not have time for second weeding of their groundnut fields as it coincides with the planting window for maize which is a major staple. The lack of second weeding of groundnut fields by smallholder farmers coupled with the low plant density are among the main causes of yield gap between farmers yield and potential yield of groundnut. Plants density adjustment is one of the less expensive and key cultural methods of weed management as higher plants density reduces resources (water, nutrient, and light) niche available to weeds which limits weed competitiveness and growth. Hence, the need for on-farm evaluation of the effect of plant density on yield and weed control in groundnut production.

Previous studies conducted on the effect of plant density in groundnut production have reported on yield, leaf spot disease and weed control (Dapaah et al., 2014; Islam et al., 2011; Naab, Boote, et al., 2009; Pande & Rao, 2002). However, most of the studies that reported an increase in groundnut yield with increasing plant density were conducted under on-station conditions with limited or no effort under on-farm conditions (Bakal et al., 2020; Dapaah et al., 2014; Naab, Boote, et al., 2009). There is also scanty information in literature on the effect of plant density on leaf spot disease in groundnut production with most of the studies conducted about 3–4 decades ago and the last study about 2 decades ago (Farrel et al., 1967; Pande & Rao, 2002; Yayock, 1981). This has renewed the interest in the effect of plant density on leaf spot disease of groundnut. Similarly, most studies on plants density effect on weed management in groundnut production have focused on weed biomass measurement and critical period for weed control (Chandolia et al., 2010; Islam et al., 2011; Kumar, 2009). Few literature exist on the effect of plant density on weed species control in groundnut production (Johnson III et al., 2005; Kharel et al., 2022). Both studies were conducted in the United State of America with focus on most problematic weeds (*Senna obtusifolia* (L.) Irwin & Barneby (Sicklepod), *Acanthospermum hispidum* DC. (Bristly starbur), *Croton glandulosus* L. (Tropic croton) and *Cyperus esculentus* L. (Yellow nutsedge)) of groundnut production in their region and they reported no significant effect of plant density on the weed species. However, literature on such studies in Africa is limited and hence the need to explore the effect of plants density beyond the selected weed species in the above studies. Such information would be important to literature and smallholder farmers in Africa especially in northern Ghana where most farmers do not have enough time for second weeding of their groundnut farms. We tested the hypothesis that adjusting the plant density of improved groundnut varieties will not affect canopy cover, grain and fodder yields, leaf spot disease, weed biomass, weed species diversity and richness.

2 | MATERIALS AND METHODS

2.1 | Study area

A 2-year on-farm experiment was conducted in the Northern region of Ghana during the 2017 and 2018 cropping seasons (Figure 1). The experiment was conducted in

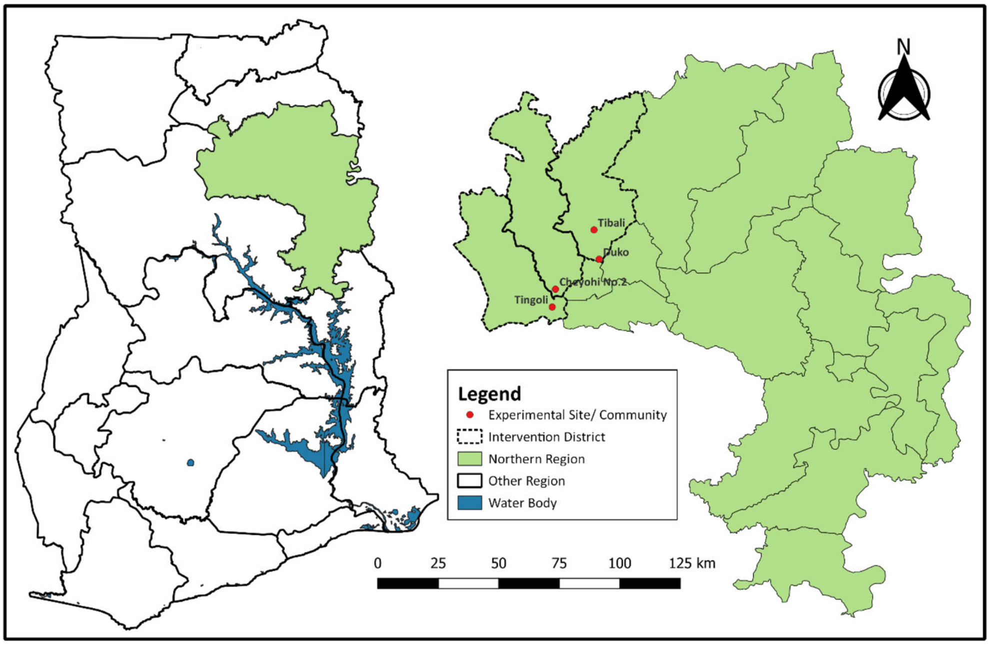

FIGURE 1 Map of Ghana showing experimental sites in the intervention communities.

Cheyohi No. 2, Tingoli, Duko and Tibali communities in the Northern region of Ghana (Figure 1). The agro-ecology of the region is Guinea (wet) savanna with mono-modal rainfall pattern. WatchDog 2900ET (Spectrum Technologies, USA) weather gauge was installed in Tingoli community to measure daily rainfall (mm) and temperature (°C) during 2017 and 2018. The WatchDog 2900ET runs on AA dry cell batteries, therefore, weather data gaps were filled by data from the nearest gauge stations thus Savanna Agricultural Research Institute gauge station about 5 km from Tingoli community. The total amount of rainfall recorded during June–October 2017 was 692.4 mm and June–October 2018 was 850.5 mm whilst the mean temperatures were 27.2 and 26.9°C for June–October 2017 and June-October2018 respectively (Figure 2).

The soils of the study areas in the Northern Region were developed from sandstones and shale with a topsoil (0–20 cm) properties of pH (5.6–6.4, 1:2.5 soil: H_2O), organic carbon (5.5–9.5 g/kg), total nitrogen (0.5–0.9 g/kg), available phosphorus (6.8–11 mg/kg), available potassium (51–109.6 mg/kg) and soil texture of loam-sandy loam (Tetteh et al., 2016).

2.2 | Experimental design

A 6 × 4 factorial treatment combination of improved groundnut varieties and plant densities in a strip plot design with four replications was used. The horizontal treatments were 6 improved groundnut varieties (Early maturity-types: Chinese, Yenyawoso, Samnut 23 and late maturity-types: Azivivi, Manipinta, Samnut 22). The early maturity varieties were 90-day maturity period whilst the late ones were 110-115-day maturity periods. The vertical treatments were four plant densities (22, 15, 11 and 9 plants/m^2). The plot size for a horizontal treatment was 70.2 m^2 whilst that of the vertical treatment varied depending on the plant density to achieve equal number of eight rows of plants per plot. The size of a plot for the vertical treatments were 9.6, 14.4, 19.2 and 24 m^2 for the plant densities of 22, 15, 11 and 9 plants/m^2 respectively. The improved groundnut varieties and plant densities were adopted and modified based on the recommended plant density for groundnut production in northern Ghana (Naab, Seini, et al., 2009). The selected communities in Figure 1 were part of intervention sites for Africa Research In Sustainable Intensification for the Next Generation (Africa RISING) project in northern Ghana and these communities were used as replicates for the experiment. The experiment was established in a technology park at the community level to engage farmers to participate, observe and learn about the technology at every level of field activity to the end of the experiment.

2.3 | Agronomic practices

The experimental fields were plowed with tractor in line with the common land preparation practice in the region. The groundnut seeds were planted at one seed per hill with spacings of 30 × 15, 45 × 15, 60 × 15, and 75 × 15 cm^2 to achieve plant densities of 22, 15, 11 and 9 plants/m^2 respectively. Weeding was done manually at 3 weeks after planting for all the plots in line with good agronomic practices.

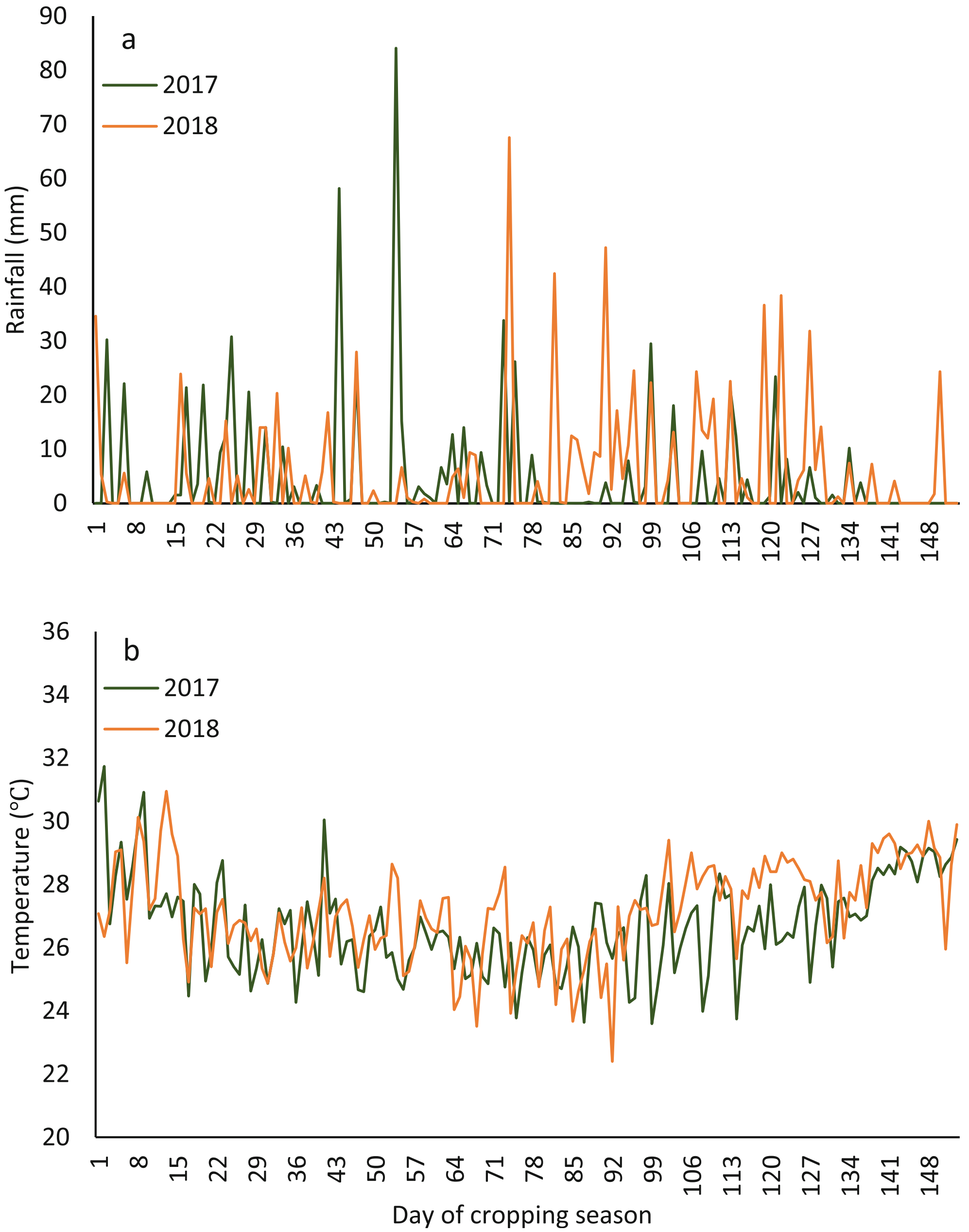

FIGURE 2 Daily rainfall (a) and temperature (b) of experimental area in Northern Region during 2017 and 2018 cropping season.

2.4 | Data collection

2.4.1 | Canopy cover

The groundnut canopy cover was measured with a quadrat of 0.5 × 0.5 m^2 in the two middle rows of each treatment plot to avoid border effect. The quadrat was placed randomly at three different locations to estimate the percentage vegetative cover for each treatment plot at 30, 40, 50, 60 days after planting (DAP) and at harvest (Daubenmire, 1959).

2.4.2 | Grain and fodder yield

At physiological maturity of the plants, the pods of plants in the middle rows of each treatment plot were harvested for grain yield data to reduce edge row effect. The pods were oven dried at 65°C to moisture content of 12%, cracked to remove the grains and measured as grain yield. Similarly, the harvested plants in the two middle rows of each treatment plot were cut at ground level, oven dried at 65°C to a constant weight and measured as fodder yield.

2.4.3 | Weed frequency, density, diversity, and biomass

Weed species frequency, density, summed dominance ratio (SDR), richness and diversity were measured with 1 × 1 m^2 quadrat. The quadrat was placed randomly at five different locations in each treatment plot to measure weed species frequency, density, SDR, and diversity using a scale of 0–4 samples where 0 = no occurrence, 1 = 1, 2 = 2–5, 3 = 6–20 and 4 = >20 plants of the weed species. The weed frequency (richness) was counted as the number of occurrences of weed species whilst the density corresponded to the scores of weed species in a quadrate. Average weed species occurrence in each treatment plot was calculated using the Summed Dominance Ratio (SDR) approach in Equation (1) (Dangol, 1991).

$$\mathrm{SDR}\,(\%) = \frac{1}{2}\left[\left(\frac{F}{\Sigma F}\right) + \left(\frac{D}{\Sigma D}\right)\right] \times 100 \tag{1}$$

where F = frequency of occurrence of a weed species within a treatment block and D = density of occurrence within a treatment block. Weed species richness was also counted as the number of weed species under a treatment plot. Weed species diversity index was calculated using Equation (2) (Hill, 1973).

$$\text{Diversity index}\,(D) = \frac{1}{\sum_{i=1}^{S} {P_i}^2} \tag{2}$$

where P_i is the proportion of individuals belonging to the group i^{th} species and S is the total number of species. In each quadrat after the weed species were identified and scored, the weeds were cut at ground level and oven dried at 70°C to a constant weight to measure weed biomass.

2.4.4 | Leaf spot disease incidence

The incidence of leaf spot disease was measured by counting the number of plants infested with leaf spot disease and total number of plants within the 2 middle rows of each treatment plot and expressed as a percentage using the Equation (3) (Gaikpa et al., 2015):

$$\text{Leaf spot incidence}(\%) = \left(\frac{\text{Number of infested plants}}{\text{Total number of plants}}\right) \times 100 \tag{3}$$

The leaf spot disease incidence per plant was also measured from the 2 middle rows of each treatment plot using systematic sampling. The first five plant stands or hills at the beginning and the last five plant stands at the end of the two middle plant rows were also excluded from the sample. Every 5th plant stand within the two middle plant rows was sampled for counting the total number of leaves and number of leaf spot-infested leaves per plant. The incidence of leaf spot per plant was calculated using Equation (4) (Gaikpa et al., 2015):

$$\text{Leaf spot incidence per plant}(\%) = \left(\frac{\text{Number of infested leaves per plant}}{\text{Total number of leaves per plant}}\right) \times 100 \tag{4}$$

2.5 | Statistical analysis

The groundnut canopy cover, grain and fodder yields, weed frequency, density, leaf spot incidence data were analyzed using Statistical Analysis System (SAS Institute, 2015). The data were analyzed on year basis using the model in Equation (5).

$$Y_{\mathrm{ijkl}} = \mu + B_{\mathrm{i}} + V_{\mathrm{j}} + \left(\mathrm{BV_{ij}}\right) + D_{\mathrm{K}} + \left(\mathrm{BD_{ik}}\right) + \left(\mathrm{VD_{JK}}\right) + \mathrm{e_{ijk}} \tag{5}$$

where Y_{ijk} is an observation, μ is experimental mean, B_i is block (community) effect, V_j is variety effect, BV_{ij} is the error effect for variety, D_k is plant density effect, DB_{ik} is error effect for plant density, VD_{jk} is variety by plant density effect and e_{ijk} is error. Treatment means of significant difference were separated using least significant difference (lsd) test at a probability level of 0.05. Pearson correlation was used to establish the relationship between grain yield and other measured variables. Correlation coefficients of 0.4 and above were considered best fitted and less than 0.4 considered less fitted. We also calculated the square of correlation coefficient and multiplied by 100 to determine the proportion of variation of Y variables attributed to X (Armstrong, 2019). We also performed Friedman's test to support the ANOVA analysis due to the small sample size of the data. The results of the Friedman's test are attached as supplementary file (Tables S1–S3, S5 and Figure S3) and the trend was similar to that of the ANOVA analysis.

3 | RESULTS

3.1 | Canopy cover

Groundnut variety showed significant effect on plant canopy cover from 30 DAP to harvest especially during 2018 (Figure 3a,b). Sumnut 22 variety recorded higher ($p < .05$) canopy cover than that of Sumnut 23 variety during all the measurement period (Figure 3b). The groundnut canopy cover showed significant response to the plant densities in both years (Figure 3c,d). In 2017, the canopy cover increased ($p < .05$) from 30 DAP to harvest with 22 plants/m^2 recording the highest canopy cover and 9 plants/m^2 recording the least (Figure 3c,d). In 2018, the significant increase in canopy cover among the plant densities followed similar trend of 2017 from 30 DAP to harvest (Figure 3c,d).

3.2 | Grain and fodder yield

Table 1 shows the effect of groundnut variety and plant density on grain and fodder yields. The groundnut variety did not show significant response to grain yield in 2017 but in 2018, grain yield varied significantly among the groundnut varieties. Manipinta groundnut variety had the highest ($p < .01$) whilst Samnut 23 variety recorded the lowest grain yield. In contrast to the grain yield, the fodder yield showed significant response among the groundnut variety in 2017 and 2018. In 2017, the fodder yield of Azivivi variety increased ($p < .01$) relative to that of Chinese variety. However, the fodder yield of Azivivi variety was not statistically different from that of Manipinta. In 2018, the fodder yield of Samnut 22, Manipinta and Azivivi were not significantly different from each other, but their fodder yields were higher ($p < .01$) than that of the other three groundnut varieties.

The plant density showed significant effect on both grain and fodder yields in 2017 and 2018 (Table 1). The grain yield increased ($p < .01$) with increasing plant density from 9 to 22 plants/m^2 in 2017 (Table 1). In 2018, grain yield of 22 plants/m^2 increased significantly relative to that of 9 and 11 plants/m^2 but was not statistically different from that of 15 plants/m^2 (Table 1). The fodder yield for 22 plants/m^2 increased significantly relative to that of 9 and 11 plants/m^2 but was not statistically different from that of 15 plants/m^2 in both 2017 and 2018 (Table 1).

3.3 | Weed frequency, density, diversity, and biomass

Table 2 shows the effect of groundnut variety and plant density on weed species frequency. The groundnut variety had no significant effect on the frequency of grass and broadleaf weed species in both years. The frequency of sedge weed species showed significant response to the groundnut variety in 2017 but it was not statistically different in 2018. Chinese variety recorded higher ($p < .01$) frequency of sedge weed species than that of the other groundnut varieties in 2017.

The plant density did not show significant effect on frequency of grass weed species in both years (Table 2).

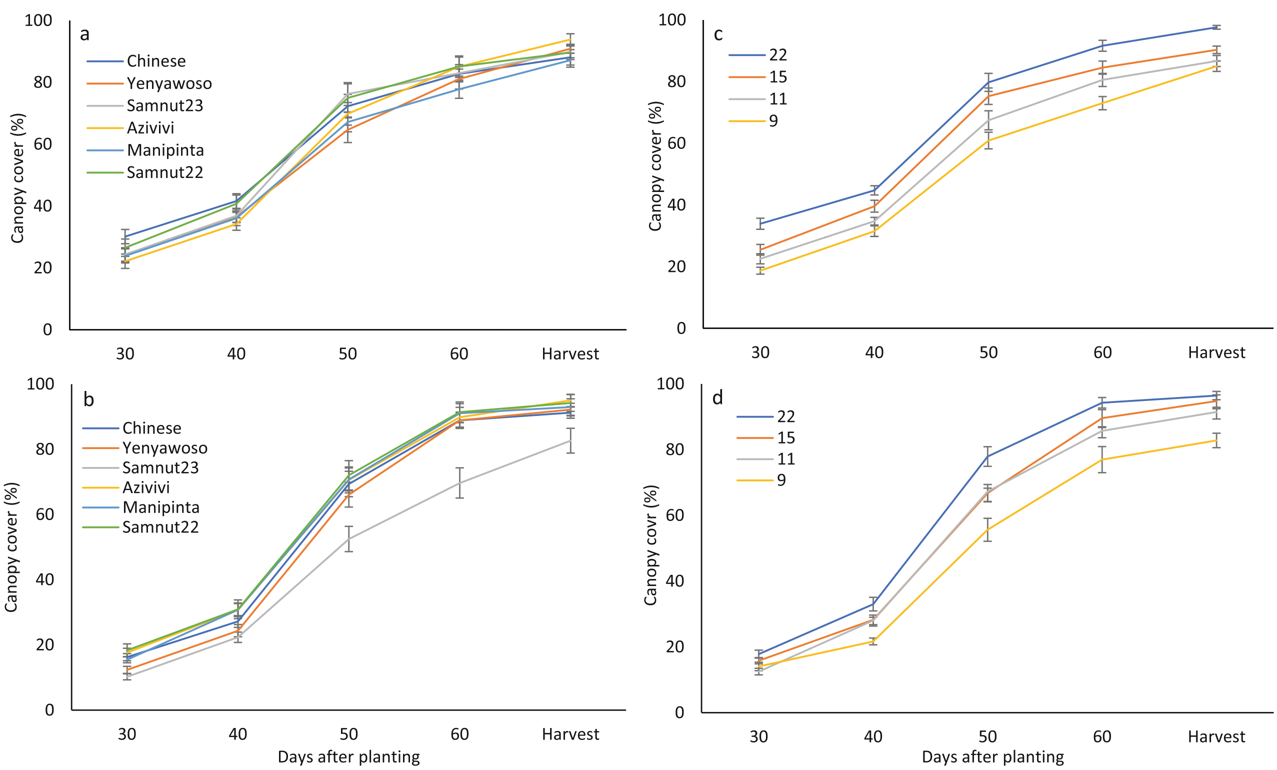

FIGURE 3 Effect of groundnut variety (a) 2017, (b) 2018 and plant density (c) 2017, (d) 2018) on canopy cover in Northern Region of Ghana. Bars represent standard error of mean.

TABLE 1 Groundnut variety and plant density effect on grain and fodder yields during 2017 and 2018 cropping seasons in Northern Region of Ghana.

	Grain yield (kg/ha)		Fodder yield (kg/ha)	
	2017	2018	2017	2018
Variety				
Chinese	889.5a	609.8bc	1236.9c	1892.9b
Yenyawoso	747.7a	638.3bc	1443.5bc	2075.1b
Samnut23	922.4a	452.2c	1507.5bc	1701.4a
Azivivi	1012.5a	840.7ab	2307.7a	3830.3a
Manipinta	943.7a	1011.4a	1938.8ab	4396.5a
Samnut22	900.7a	816.2ab	1679.7bc	4426.3a
Standard error	*130.31*	*89.00*	*167.88*	*213.49*
p-value	*ns*‡	**	**	***
Plant density (plants/m^2)				
22	1212.0a	971.9a	2093.a	3881.5a
15	964.0b	748.6ab	1799.4ab	3383.9ab
11	737.2c	623.8b	1404.6b	2487.7b
9	697.7c	568.2b	1445.7b	2461.9b
Standard error	*54.82*	*92.80*	*153.69*	*354.80*
p-value	***	*	*	*

Note: Values with same letters in a column under a parameter are not significantly different from each other according to lsd test.
‡$p > .05$; *$p \leq .05$; **$p \leq .01$; ***$p \leq .001$.

Similarly in 2017, the frequency of sedge weed species was not significant among the plant densities, but it showed significant response to plant density in 2018 (Table 2). The frequency of sedge weed species for 22 plants/m^2 was significantly less compared with that of the 9 plants/m^2, but it was not statistically different from that of 11 and 15 plants/m^2 in 2018 (Table 2). The frequency of the broadleaf weed species also showed significant response to the plant density in 2017 and 2018 (Table 2). The 22 plants/m^2 recorded the least ($p < .01$) broadleaf weed species frequency relative to the other plant densities in 2017 and 2018 (Table 2). The broadleaf weed species frequency decreased ($p < .01$) with increasing plant density from 9 to 22 plants/m^2 in 2017 (Table 2).

The effect of groundnut variety and plant density on weed species density is shown in Table 3. The grass and broadleaf weed species density did not show significant response among the groundnut varieties in both years. However, the sedge weed species density was significant among the groundnut varieties in both years. In 2017, the sedge weed species density of Chinese variety was higher ($p < .01$) than that of the other groundnut varieties. Yenyewoso variety recorded higher ($p < .05$) sedge weed species density relative to that Samnut 22 variety in 2018. However, the sedge species density of Yenyewoso variety was not statistically different from that of Chinese, Samnut 22, Azivivi and Manipinta varieties in 2018.

The plant density had no significant effect on grass and sedge weed species density in both years, but the broadleaf species density showed significant response to plant density in 2017 and 2018 (Table 3). The broadleaf species density decreased ($p < .01$) with increasing plant density from 9 to 22 plants/m^2 in 2017 and 2018 (Table 3).

Table 4 shows the effect of plant density on weed species dominance (SDR), richness and diversity in both 2017 and 2018. The weed species were examined in 3 main groups of grass, sedge, and broadleaf. The total number of weed species identified in 2017 and 2018 were 49 and 38 respectively. Eight grass species were recorded in 2017 compared with nine in 2018. *Bracharia deflexa* (Schumach.) C.E Hubbard ex Robyns (Guinea millet) grass species was only recorded in 2017 whilst *Eleusine indica* Gaertn. (Goose grass), *Eragrostis ciliaris* (Linn.) R. Br. (Love grass) and *E. tremula* Hochst. ex Steud (Love grass). grass species were recorded in only 2018. Similarly, *Dactylotenium aegyptium* (Linn.) P. Beauv. (Crowfoot grass) grass species was recorded in only 11 plants/m^2 during 2017 but in 2018 it occurred in

TABLE 2 Weed species frequency (number/m^2) as affected by groundnut variety and plant density in Northern Region of Ghana during 2017 and 2018 cropping seasons.

	Grass		Sedge		Broadleaf	
	2017	2018	2017	2018	2017	2018
Variety						
Chinese	0.6a	1.3a	1.3a	1.2a	6.6a	8.2a
Yenyawoso	0.4a	0.9a	0.8a	1.3a	6.4a	7.7a
Samnut23	0.6a	1.4a	0.3bc	1.3a	7.1a	7.2a
Azivivi	0.3a	1.0a	0.3bc	0.9a	6.3a	5.8a
Manipinta	0.2a	0.8a	0.6b	0.9a	6.6a	7.0a
Samnut22	0.3a	1.2a	0.1c	0.5a	5.6a	6.8a
Standard error	*0.18*	*0.22*	*0.15*	*0.18*	*0.49*	*0.77*
p-value	*ns*‡	*ns*	***	*ns*	*ns*	*ns*
Plant density (plants/m^2)						
22	0.3a	0.8a	0.5a	0.6b	4.9d	4.2c
15	0.5a	1.2a	0.5a	1.0ab	6.0c	6.4b
11	0.3a	1.1a	0.5a	1.4a	6.b	8.3a
9	0.5a	1.3a	0.7a	1.0ab	7.8a	9.5a
Standard error	*0.13*	*0.17*	*0.08*	*0.15*	*0.25*	*0.50*
p-value	*ns*	*ns*	*ns*	*	***	***

Note: Values with same letters in a column under a parameter are not significantly different from each other according to lsd test.
‡$p > .05$; *$p \leq .05$; ***$p \leq .001$.

only 15 plants/m^2. *Digitaria horizontalis* Willd. (Crab grass) grass species was also recorded in 22 plants/m^2 during 2017 whilst during 2018 *Seteria Pumila* (Poir.) Roem & Schult. (Cattail grass) grass species occurred in only 9 plants/m^2. The grass SDR for 2017 was less compared to that of 2018. *B. deflexa* recorded the highest grass SDR in 2017 whilst *Panicum laxum* Sw. (Lax panic grass) had the highest grass SDR in 2018.

Nine sedge species were identified in 2017 as against 3 sedge species in 2018 (Table 4). *C. escunlentus*, *Mariscus cylindristachyus* Steud., *C. iria* Linn. (Rice flatsedge) and *Kyllinga squamulata* Thonn. ex Vahl (Asian spikesedge) sedge species were identified in only 2017 (Table 4). Similarly in 2017, *M. cylindristachyus* and *C. iria* sedge species were recorded in only 9 and 15 plants/m^2 treatments respectively (Table 4). In 2018, *K. pumila* Michx. (Low spikesedge) sedge species occurred in only 15 plants/m^2 treatment (Table 4). The sedge SDR recorded in 2017 was lower compared with that of 2018 (Table 4). *C. escunlentus* and *C. rotundus* Linn. recorded the highest sedge SDR in 2017 and 2018 respectively (Table 4). In general, the SDR for sedge species increased with increasing plant density but the SDR for *K. bulbosa* Beauv. sedge species reduced with increasing plant density in both years (Table 4).

Thirty-two broadleaf species were recorded in 2017 relative to twenty-six broadleaf species identified in 2018 (Table 4). *Hibiscus asper* Hook. f. (Bush roselle), *H. suaveolens*, *Monechma ciliatum* (Jacq.) Milne-Redhead. (Hunglade) and *Physalis angulata* Linn. (Wildcape gooseberry) broadleaf species were recorded in only 2017 whilst *Ipomoea triloba* Linn. (Littlebell), *Sida acuta* Burm. f. (Broom weed) and *Spigelia anthelma* Linn. (Pinkweed) broad leaf species were also identified in 2018 (Table 4). *H. asper*, *H. suaveolens* and *M. ciliatum* broadleaf species occurred in only 9 plants/m^2 during 2017 and *I. eriocarpa* R. Br. (Tiny morning glory) broadleaf species also occurred in only 9 plants/m^2 during 2018 (Table 4). The broadleaf SDR for 2017 was higher than that of 2018 with *Ludwigia decurrens* Walt. Syn. (Water primrose) and *M. villosus* recording the highest broadleaf SDR in 2017 and 2018 respectively (Table 4). The broadleaf SDR response to plant density was not consistent in 2017 but in 2018, it declined with increasing plant density (Table 4). Similarly, the SDR for *C. benghalensis* and *Stachytarpheta cayennensis* (L. C. Rich.) Schau. (Blue rat's tail) declined with increasing plant density in both years and vice versa for the SDR of *M. villosus* in both years (Table 4).

TABLE 3 Weed species density (score/m^2) as affected by groundnut variety and plant density in Northern Region of Ghana during 2017 and 2018 cropping seasons.

	Grass		Sedge		Broadleaf	
	2017	2018	2017	2018	2017	2018
Variety						
Chinese	0.9a	2.3a	2.4a	2.3a	13.9a	18.1a
Yenyawoso	0.6a	1.6a	1.3b	2.4a	14.3a	16.6a
Samnut23	0.8a	2.5a	0.6bc	2.1a	14.6a	17.1a
Azivivi	0.3a	1.8a	0.4c	1.4ab	12.4a	15.3a
Manipinta	0.4a	1.5a	1.0bc	1.5ab	13.9a	16.3a
Samnut22	0.3a	1.8a	0.2c	0.8b	11.2a	14.9a
Standard error	*0.25*	*0.35*	*0.28*	*0.34*	*1.44*	*1.42*
p-value	*ns*‡	*ns*	***	*	*ns*	*ns*
Plant density (plants/m^2)						
22	0.3a	1.6a	0.8a	1.1a	10.0c	8.8c
15	0.7a	2.0a	0.9a	1.7a	13.1b	16.0b
11	0.4a	2.0a	0.9a	2.5a	14.2b	19.7a
9	0.8a	2.0a	1.3a	1.7a	16.3a	20.8a
Standard error	*0.21*	*0.22*	*0.17*	*0.38*	*0.58*	*0.86*
p-value	*ns*	*ns*	*ns*	*ns*	***	***

Note: Values with same letters in a column under a parameter are not significantly different from each other according to lsd test.
‡$p > .05$; *$p \leq .05$; ***$p \leq .001$.

The weed species diversity index decreased with increasing plant density from 9 to 22 plants/m^2 in 2017. A similar trend of weed species diversity index for 2017 was also observed in 2018 with plant densities 22 and 9 plants/m^2 recording the least and highest weed species diversity indices respectively (Table 4). The weed richness also decreased with increasing plant density from 9 to 22 plants/m^2 in both years (Table 4).

The weed biomass did not show significant response to the groundnut variety in both years, but the plant density had significant effect on weed biomass (Table 5). Generally, the weed biomass recorded in 2017 was higher than in 2018. The weed biomass decreased ($p < .01$) with increasing plant density from 9 to 22 plants/m^2 in both years (Table 5).

3.4 | Incidence of leaf spot disease

The incidence of leaf spot disease was significant among the groundnut varieties, but it did not show significant response to plant density (Table 5). In 2017 the leaf spot incidence among the groundnut varieties was significant with Chinese variety recording higher ($p < .01$) incidence of leaf spot disease than the other varieties (Table 5). The incidence of leaf spot disease per plant among the groundnut varieties was also significant in both years. The leaf spot per plant was higher ($p < .01$) in the Chinese variety relative to the other varieties in both years (Table 5). However, in 2018 the leaf spot per plant of Chinese variety was not statistically different from that of the Yenyewoso variety (Table 5).

3.5 | Correlation among yield, weed, canopy cover and leaf spot

Table 6 shows correlation among grain, fodder, canopy cover, weed, and leaf spot disease during the 2 years. The grain yield showed positive and significant correlation with fodder yield, canopy cover at 30, 50, and 60 DAP in both years. However, the grain yield showed negative and significant correlation with broadleaf weed species during 2017 and 2018. The weed biomass significantly and negatively correlated with canopy cover in both years. However, it showed positive and significant correlation with broadleaf species during both years. The canopy cover also showed negative and significant correlation with broadleaf and sedge species in 2017 and 2018. The incidence of leaf spot disease showed positive and

TABLE 4 Weed species incidence, richness and diversity as affected by groundnut plant density in Northern Region of Ghana during 2017 and 2018 cropping seasons.

		2017				2018			
		Plant density (plants/m^2)							
Weed species	**Authority**	22	15	11	9	22	15	11	9
GRASSES		**4.8**	**5.9**	**3.0**	**5.2**	**10.9**	**12.1**	**9.0**	**10.0**
Bracharia lata	(Schumach.) C.E Hubbard	-	0.4	1.7	2.1	1.0	1.6	0.3	1.2
Bracharia deflexa	(Schumach.) C.E Hubbard ex Robyns	1.3	2.5	-	0.5	-	-	-	-
Dactylotenium aegyptium	(Linn.) P. Beauv.	-	-	0.4	-	-	1.0	-	-
Digitaria horizontalis	Willd.	1.3	-	-	-	1.5	2.9	2.6	2.0
Eleusine indica	Gaertn.	-	-	-	-	1.2	1.1	-	0.3
Eragrostis ciliaris	(Linn.) R.Br.	-	-	-	-	-	-	1.6	0.8
Eragrostis tremula	Hochst. ex Steud.	-	-	-	-	-	-	0.3	0.5
Hackelochloa granularis	(Linn.) O. Ktze.	0.6	-	0.4	0.5	-	-	-	-
Panicum laxum	Sw.	0.6	0.9	-	1.4	6.7	3.4	2.7	3.1
Paspalum scrobiculatum	Linn.	0.6	-	-	-	0.4	2.1	1.5	1.2
Setaria pumila	(Poir.) Roem & Schult	0.6	2.2	0.5	0.8	-	-	-	0.9
SEDGES		**8.0**	**7.4**	**7.4**	**7.5**	**9.6**	**8.4**	**11.1**	**8.8**
Cyperus escunlentus	Linn.	5.0	2.6	4.5	4.2	-	-	-	-
Mariscus cylindristachyus	Steud.	-	-	-	0.7	-	-	-	-
Cyperus iria	Linn.	-	0.6	-	-	-	-	-	-
Cyperus rotundus	Linn.	0.6	-	0.9	-	6.7	6.1	7.4	5.6
Fimbristylis ferruginea	(Linn.) Vahl	0.7	-	-	-	-	-	-	-
Fuirena ciliaris	(Linn.) Roxb.	-	-	0.4	1.0	-	-	-	-
Kyllinga bulbosa	Beauv.	0.7	-	-	0.8	2.9	1.8	3.6	3.1
Kyllinga pumila	Michx.	0.9	2.3	0.5	0.4	-	0.4	-	-
Kyllinga squamulata	Thonn. ex Vahl	-	1.9	1.0	0.5	-	-	-	-
BROADLEAVES		**87.2**	**86.7**	**89.6**	**87.2**	**79.5**	**79.6**	**79.9**	**81.2**
Ageratum conyzoides	Linn.	9.7	6.6	6.6	6.1	4.8	5.6	5.2	4.8
Alysicarpus vaginalis	(L.) DC.	-	0.6	-	-	-	-	-	-
Amaranthus spinosus	Linn.	-	-	0.4	-	-	-	-	-
Aneilema aequinoctiale	(P. Beauv.) Kunth	1.3	0.6	0.9	0.5	-	-	-	-
Bidens pilosa	Linn.	4.4	3.9	3.0	3.0	-	-	-	-
Boerhavia diffusa	L.	-	-	-	-	-	0.3	0.3	0.3
Cleome viscosa	L.	-	-	0.4	-	-	-	-	-
Commelina benghalensis	L.	3.7	5.8	8.1	5.2	4.8	3.5	5.0	5.8
Corchorus olitorius	L.	6.7	6.4	5.8	5.0	7.6	8.5	7.1	7.7
Crotalaria retusa	Linn.	-	-	1.2	0.4	-	-	-	-
Euphorbia heterophylla	Linn.	2.4	1.3	3.5	2.4	-	1.0	2.8	2.0
Euphorbia hirta	Linn.	1.1	0.4	0.9	1.1	0.4	2.4	0.3	1.5
Gomphrena celosioides	Mart.	1.1	1.3	0.4	0.8	1.0	0.3	0.3	0.4
Hibiscus asper	Hook. f.	-	-	-	0.4	-	-	-	-
Hyptis saveolens	Poit.	-	-	-	0.5	-	-	-	-
Hyptis spicigera	Lam.	8.5	7.8	10.2	10.0	9.2	10.5	10.0	9.1

TABLE 4 (Continued)

		2017				2018			
		Plant density (plants/m^2)							
Weed species	**Authority**	**22**	**15**	**11**	**9**	**22**	**15**	**11**	**9**
Ipomoea eriocarpa	R. Br.	-	0.9	1.2	-	-	-	-	0.3
Ipomoea triloba	Linn.	-	-	-	-	0.4	-	0.3	-
Leucas martinicensis	(Jacq.) Ait.f.	6.3	8.9	4.7	6.7	1.9	2.1	4.1	4.2
Ludwigia decurrens	Walt. Syn.	16.0	14.4	11.7	10.0	13.3	11.9	9.6	9.4
Mitracarpus villosus	(Sw.) DC.	10.7	8.8	8.9	10.0	12.0	11.2	9.3	9.9
Mollugo nudicaulis	Lam.	-	-	0.8	1.2	1.0	1.5	1.4	-
Monechma ciliatum	(Jacq.) Milne-Redhead	-	-	-	1.2	-	-	-	-
Oldenlandia corymbosa	Linn.	3.0	2.2	2.2	2.7	7.4	2.8	5.4	5.1
Phyllanthus amarus	Schumach. & Thonn.	2.6	1.0	1.6	2.1	2.6	0.3	3.3	3.1
Physalis angulata	Linn.	0.6	1.2	0.4	0.7	-	-	-	-
Portulaca quadrifida	Linn.	2.4	4.8	4.2	5.7	4.4	5.9	3.2	5.1
Schwenckia americana	L.	0.6	1.5	0.5	1.4	2.1	4.3	3.3	2.9
Scoparia dulcis	Linn.	0.7	2.2	1.4	0.8	2.6	2.3	2.8	2.4
Senna obtusifolia	(L.) Irwin & Barneby	-	-	0.4	0.7	-	-	0.5	1.1
Sida acuta	Burm. f.	-	-	-	-	-	0.4	0.3	0.3
Spigelia anthelma	Linn.	-	-	-	-	-	-	0.7	0.3
Stachytarpheta cayennensis	(L. C. Rich) Schau.	4.4	6.2	8.3	6.0	1.4	2.4	3.7	3.9
Tridax procumbens	Linn.	-	-	0.4	0.5	0.8	-	0.5	-
Triumfetta cordifolia	A. Rich.	1.1	-	1.0	1.6	-	0.3	0.3	0.4
Vernonia ambiqua	Kotschy & Peyr	-	-	0.4	0.9	1.9	1.8	0.3	1.4
Total		**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**
Weed species richness		*31.0*	*29.0*	*37.0*	*39.0*	*26.0*	*30.0*	*33.0*	*33.0*
Weed species diversity index		*13.5*	*15.0*	*15.7*	*17.6*	*14.9*	*15.3*	*17.3*	*17.8*

Note: The bold vaules are to distinquish the scores for the group (grass, sedge and broadleaf) weed species from the individual weed species.

significant correlation with grass weed species in both years.

4 | DISCUSSION

4.1 | Canopy cover

The statistical difference observed among the groundnut varieties could be due to the genetic and phenotypic expression of the varieties. The higher canopy cover recorded by the Samnut 22 relative to lower canopy cover of Samnut 23 at all growth stages could be explained by the biomass production and spreading growth habit of the two varieties. In line with our results, another study reported a significant increase in canopy spread of Samnut 22 relative to samnut 23 at 3, 6, 9 and 12 weeks after planting (Bala et al., 2011). The significant increase in canopy cover among the plant densities in both years could be explained by the number of plants per unit area and the more the plants per unit area the higher the canopy cover. In support of our results, other studies have reported higher canopy cover with more plants per unit area compared with low plants per unit area (Johnson III et al., 2005; Kharel et al., 2022; Tillman et al., 2006).

4.2 | Grain and fodder yields

The significant effect of variety on grain and fodder yields may also be attributed to differences in the genetic and phenotypic expressions of the groundnut varieties. The difference to physiological maturity period of varieties could also contribute to the variation in grain and fodder yields of the varieties as more number of days to physiological allows more time for accumulation and

TABLE 5 Effect of groundnut plant density on weed biomass, leaf spot disease incidence in Northern Region of Ghana during 2017 and 2018 cropping seasons.

	Weed biomass (g/m^2)		Leaf spot incidence (%)		Leaf spot incidence per plant (%)	
	2017	2018	2017	2018	2017	2018
Variety						
Chinese	1146.9a	126.3a	21.4a	16.7a	40.3a	60.2a
Yenyawoso	1228.8a	128.8a	15.1b	14.1a	24.3b	56.1ab
Samnut23	1073.1a	158.1a	16.8b	15.4a	23.1bc	42.0c
Azivivi	932.5a	151.9a	9.9c	13.0a	10.9c	34.0c
Manipinta	779.4a	133.1a	14.7b	13.1a	21.6bc	38.9c
Samnut22	710.6a	98.8a	15.8b	11.6a	23.1bc	44.4bc
Standard error	*128.10*	*13.07*	*0.79*	*1.39*	*4.42*	*3.90*
p-value	*ns*‡	*ns*	***	*ns*	**	**
Plant density (plants/m^2)						
22	426.7d	64.2d	14.4a	14.5a	24.1a	46.0a
15	752.1c	117.1c	14.7a	14.2a	24.7a	45.0a
11	1167.1b	157.9b	16.4a	13.6a	24.0a	48.4a
9	1568.3a	192.1a	17.a	13.5a	22.8a	44.4a
Standard error	*68.51*	*6.88*	*0.82*	*1.50*	*1.23*	*2.58*
p-value	***	***	*ns*	*ns*	*ns*	*ns*

Note: Values with same letters in a column under a parameter are not significantly different from each other according to lsd test.
‡$p > .05$; **$p \le .01$; ***$p \le .001$.

partition of dry matter into yield. The variations in grain and fodder yields among the varieties are also useful for breeding programs. These results support the findings of earlier studies that late maturing groundnut varieties produce higher grain and fodder yields relative to early maturing groundnut varieties (Abdul Rahman, Ansah, et al., 2019; Naab, Boote, et al., 2009). In contrast to our results, other studies have reported significant increase in grain yield of early maturing groundnut varieties relative to those of late maturing groundnut varieties (Kamara et al., 2011; Tarawali & Quee, 2014).

The significant increase in grain and fodder yields with increasing plant density could be due to the greater number of plants per unit area of land. The higher the number of plants per unit area of land the higher the number of pods and plant biomass per unit area of land which translate into higher grain and fodder yields. Several studies have reported significant increase in grain and fodder yields of groundnut with increasing plants per unit area (Bakal et al., 2020; Dapaah et al., 2014; Naab, Boote, et al., 2009). However, this result contrast the findings of other studies that have reported high groundnut pod yield with lower plant density relative to higher plant density (Cordeiro et al., 2023; Kumar, 2009).

The significant increase in grain and fodder yields could also be explained by the positive and significant correlation between grain and fodder yields in both years. This relationship explains about 16%–36% variation in the grain and fodder yields recorded during both years.

4.3 | Weed frequency, density, diversity, and biomass

The statistical difference on the frequency and density of sedge weed species observed among the ground varieties could be attributed to genetic traits and growth habit of the varieties. The spreading growth of Samnut 22 ensures early closure of canopy which affect niches available for weed species growth. In line with this results, other studies have reported that crop varieties do not only differ in their production potential, but they differ in their competitive ability to weeds based on their variations in rapid development of foliage and early closer of canopy during vegetative growth (Bussan et al., 1997; Priya et al., 2015).

Similarly, the effect of plant density on the frequency and density of sedge and broadleaf species could be explained by the difference in number of plants per unit area. The higher the number of plants per unit area, the earlier the plant canopy cover closes and the more competitive the plants are against weed growth. Johnson III

TABLE 6 Correlation among yield, weed, canopy cover and leaf spot disease incidence in Northern Region of Ghana, 2017 and 2018 cropping season.

	GYD	FYD	WBM	CP3	CP4	CP5	CP6	CPH	FGR	FSG	FBL	DGR	DSG	DBL	LSD	LSP
2017																
GYD	1															
FYD	0.41^{**}	1														
WBM	-0.30^{**}	-0.24^{*}	1													
CP3	0.36^{**}	-0.09^{ns}	-0.40^{**}	1												
CP4	0.27^{**}	0.06^{ns}	-0.45^{**}	0.55^{**}	1											
CP5	0.15^{ns}	0.01^{ns}	-0.40^{**}	0.50^{**}	0.62^{**}	1										
CP6	0.26^{**}	0.20^{*}	-0.50^{**}	0.48^{**}	0.62^{**}	0.71^{**}	1									
CPH	0.24^{*}	0.18^{ns}	-0.50^{**}	0.33^{**}	0.53^{**}	0.36^{**}	0.56^{**}	1								
FGR	0.04^{ns}	-0.19^{ns}	0.23^{*}	-0.03^{ns}	-0.03^{ns}	0.14^{ns}	-0.01^{ns}	-0.09^{ns}	1							
FSG	-0.12^{ns}	-0.03^{ns}	0.18^{ns}	-0.17^{ns}	-0.13^{ns}	-0.30^{**}	-0.27^{**}	-0.08^{ns}	0.03^{ns}	1						
FBL	-0.47^{**}	-0.02^{ns}	0.49^{**}	-0.52^{**}	-0.43^{**}	-0.39^{**}	-0.34^{**}	-0.34^{**}	0.12^{ns}	0.27^{**}	1					
DGR	-0.01^{ns}	-0.14^{ns}	0.28^{**}	-0.12^{ns}	-0.07^{ns}	0.09^{ns}	-0.03^{ns}	-0.11^{ns}	0.89^{**}	0.07^{ns}	0.18^{ns}	1				
DSG	-0.15^{ns}	-0.05^{ns}	0.20^{*}	-0.11^{ns}	-0.10^{ns}	-0.29^{**}	-0.22^{*}	-0.06^{ns}	0.03^{ns}	0.93^{**}	0.26^{**}	0.05^{ns}	1			
DBL	-0.37^{**}	0.10^{ns}	0.40^{**}	-0.50^{**}	-0.40^{**}	-0.32^{**}	-0.24^{*}	-0.31^{**}	0.05^{ns}	0.31^{**}	0.82^{**}	0.13^{ns}	0.27^{**}	1		
LSD	-0.18^{ns}	-0.68^{**}	0.21^{*}	0.12^{ns}	0.03^{ns}	0.07^{ns}	-0.16^{ns}	-0.24^{*}	0.35^{**}	0.17^{ns}	0.03^{ns}	0.31^{**}	0.24^{*}	-0.06^{ns}	1	
LSP	$-0.12^{ns‡}$	-0.32^{**}	0.05^{ns}	0.17^{ns}	0.22^{*}	0.16^{ns}	-0.03^{ns}	-0.15^{ns}	0.14^{ns}	0.18^{ns}	-0.05^{ns}	0.18^{ns}	0.22^{*}	0.05^{ns}	0.46^{**}	1
2018																
GYD	1															
FYD	0.63^{**}	1														
WBM	-0.32^{**}	-0.35^{**}	1													
CP3	0.25^{**}	0.47^{**}	-0.28^{**}	1												
CP4	0.14^{ns}	0.41^{**}	-0.24^{*}	0.46^{**}	1											
CP5	0.36^{**}	0.37^{**}	-0.30^{**}	0.51^{**}	0.60^{**}	1										
CP6	0.39^{**}	0.39^{**}	-0.35^{**}	0.39^{**}	0.49^{**}	0.75^{**}	1									
CPH	0.32^{**}	0.35^{**}	-0.32^{**}	0.38^{**}	0.50^{**}	0.65^{**}	0.72^{**}	1								
FGR	-0.14^{ns}	-0.20^{*}	0.09^{ns}	-0.15^{ns}	-0.20^{ns}	-0.20^{*}	-0.27^{**}	-0.14^{ns}	1							
FSG	-0.34^{**}	-0.44^{**}	0.27^{**}	-0.32^{**}	-0.23^{*}	-0.37^{**}	-0.34^{**}	-0.35^{**}	0.06^{ns}	1						
FBL	-0.49^{**}	-0.4^{**}	0.43^{**}	-0.24^{*}	-0.21^{*}	-0.31^{**}	-0.38^{**}	-0.31^{**}	0.09^{ns}	0.34^{**}	1					
DGR	-0.13^{ns}	-0.22^{*}	0.07^{ns}	-0.15^{ns}	-0.17^{ns}	-0.15^{ns}	-0.19^{ns}	-0.07^{ns}	0.93^{**}	0.03^{ns}	0.08^{ns}	1				

(Continues)

TABLE 6 (Continued)

	GYD	FYD	WBM	CP3	CP4	CP5	CP6	CPH	FGR	FSG	FBL	DGR	DSG	DBL	LSD	LSP
DSG	-0.31^{**}	-0.46^{**}	0.20^{*}	-0.34^{**}	-0.28^{**}	-0.40^{**}	-0.34^{**}	-0.36^{**}	0.17^{ns}	0.90^{**}	0.33^{**}	0.17^{ns}	1			
DBL	-0.47^{**}	-0.37^{**}	0.51^{**}	-0.22^{*}	-0.16^{ns}	-0.32^{**}	-0.37^{**}	-0.28^{**}	0.16^{ns}	0.39^{**}	0.86^{**}	0.16^{ns}	0.39^{**}	1		
LSD	-0.19^{ns}	-0.11^{ns}	-0.19^{ns}	-0.09^{ns}	-0.07^{ns}	-0.26^{*}	-0.20^{*}	-0.08^{ns}	-0.10^{ns}	0.16^{ns}	0.13^{ns}	-0.11^{ns}	0.13^{ns}	0.10^{ns}	1	
LSP	-0.19^{ns}	-0.28^{**}	-0.02^{ns}	-0.04^{ns}	0.05^{ns}	0.02^{ns}	0.01^{ns}	0.06^{ns}	0.39^{**}	0.09^{ns}	0.21^{*}	0.49^{**}	0.18^{ns}	0.22^{*}	0.10^{ns}	1

Abbreviations: CP3, canopy cover at 30 days after planting; CP4, canopy cover at 40 days after planting; CP5, canopy cover at 50 days after planting; CP6, canopy cover at 60 days after planting; CPH, canopy cover at harvest; DBL, density of broadleaf; DGR, density of grass; DSG, density of sedge; FBL, frequency of broadleaf; FGR, frequency of grass; FSG, frequency of sedge; FYD, fodder yield; GYD, grain yield; LSD, leaf spot disease incidence; LSP, leaf spot disease incidence per plant; WBM, weed biomass.

$^{‡}p > .05$; $^{*}p \le .05$; $^{**}p \le .01$.

et al. (2005) reported significant difference in the total density of weed species of narrow and wide spaced groundnut plants study conducted in the United State of America. However, the same authors reported no significant difference in the individual weed species densities between the narrow and wide spacing of the groundnut plants. Similarly, another study conducted in India on weed management with varying groundnut densities showed no significant response in weed density among the different plant densities (Chandolia et al., 2010).

The sedge and broadleaf species frequency and density showed negative and significant correlation with canopy cover, indicating that an increase in plant canopy cover results in decline of broadleaf and sedge species frequency and density and vice versa. The relationships accounted for variations of about 14% for sedge frequency, 19% for broadleaf frequency and 18% for broadleaf density.

The difference in SDR between the 2 years could be attributed to the difference in climatic conditions of the 2 years. The presence of some weed species with increasing plant density could be explained by the competition for resources (nutrient, light and water) from the number of plants per unit area which affects niches available for weed growth. The higher SDR recorded by the broadleaf species relative to the grass and sedge species could be due to the C3 plant nature of the broadleaf species as they require less light for growth, and this make them tolerant to shading effect compared to the other weed species. In line with our results, other studies in northern Ghana have reported higher SDR for broadleaf species relative to grass and sedge weed species (Abdul Rahman, Larbi, et al., 2019; Berdjour et al., 2020).

The decline in SDR values for *K. bulbosa*, *C. benghalensis*, and *S. cayennensis* with increasing plant density could be explained by the limited access to resources especially light to the surface of the soil which affects germination of their seeds in the soil. Other studies have reported significant response of *C. benghalensis* and *S. cayennensis* seeds to light for germination (Dias-Filho, 1996; Walker & Evenson, 1985). Planting groundnut at higher plant density has a potential of reducing the growth of *C. benghalensis* and *S. cayennensis* weeds which are difficult to control even with chemical application. The increase in SDR of *M. villosus* with increasing plant density was not clear to us on what might be cause of this trend. Further studies to explore the effect plant density on *M. villosus* is warranted to better understand the trend observed in this study.

The significant reduction in weed biomass with increasing plant density could be due to the limited resources such as nutrient, light and water available for weed growth in the higher plant density. The weed biomass was also significant and negatively correlated with canopy cover which implies that as plant canopy cover increases, weed biomass decreases and vice versa. This relationship accounted for about 12%–25% variation in the weed biomass among the plant densities. This result supports the findings that increased plant density of crops results in reduction weed growth (Jat et al., 2011; Johnson III et al., 2005; Kumar, 2009). However, other studies have also reported no statistical difference among groundnut plant densities on weed control (Chandolia et al., 2010; Kharel et al., 2022).

4.4 | Incidence of leaf spot disease

The statistical difference among the groundnut varieties could be due to the genetic, environment or combination of both. The high incidence of leaf spot disease recorded under the Chinese variety relative to the other varieties is in consonance with earlier report that the Chinese variety is susceptible to leaf spot disease whilst the others are moderately resistant to leaf spot disease (Gaikpa et al., 2015). Other studies have also reported significant response of groundnut varieties to leaf spot disease (Ambang et al., 2011; Anco et al., 2020; Pande & Rao, 2002). The incidence of leaf spot disease showed positive and significant correlation with the frequency and density of grass weed species indicating that higher grass weed species correspond to higher incidence of leaf spot disease in groundnut and vice versa. The relationship contributed to about 12%–24% variation in leaf spot disease among the groundnut varieties.

The groundnut variety showed significant response to canopy cover, grain and fodder yields, weed species frequency and density and incidence of leaf spot disease. The late maturity varieties (Manipinta, Samnut 22 and Azivivi) recorded higher canopy cover, grain and fodder yields relative to the other varieties. However, the same varieties recorded the least sedge weed species frequency and density as well as incidence of leaf spot disease. Plant density also had significant effect on canopy cover, grain and fodder yields, broadleaf weed species frequency, density and weed biomass. The canopy cover, grain and fodder yields increased with increasing plant density but broadleaf weed species frequency, density and weed biomass declined with increasing plant density. Similarly, the weed species richness and diversity declined with increasing plant density. Grain yield showed negative and significant correlation with broadleaf weed species frequency, density and weed biomass. The results suggest that both early and late maturity groundnut variety can be planted at a density of 22 plants/m^2 to increase grain and fodder yields whilst reducing weed species richness, diversity, and growth especially broadleaf species (*C. benghalensis* and *S. cayennensis*) through early closure of plant canopy cover in northern Ghana and similar agro-ecology in West Africa.

AUTHOR CONTRIBUTIONS

Conceptualization: Asamoah Larbi and Nurudeen Abdul Rahman. *Methodology and data curation*: Nurudeen Abdul Rahman, Asamoah Larbi, Paul Tanzubil, Fred Kizito, Irmgard Hoeschle-Zeledon. *Writing original draft, review and editing*: Nurudeen Abdul Rahman, Asamoah Larbi, Paul Tanzubil, Fred Kizito, Irmgard Hoeschle-Zeledon.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are publicly available in Harvard Dataverse at https://doi.org/10.7910/DVN/MQHCRU.

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REFERENCES

Abdul Rahman, N., Ansah, T., Osuman, A. S., Stephen, F., & Amppiah, A. (2019). Improved *Arachis hypogaea* variety effect on grain yield, fodder quality and livestock growth. *Agriculture and Natural Resources*, *53*, 244–250.

Abdul Rahman, N., Larbi, A., Opoku, A., Tetteh, F. M., & Hoeschle-Zeledon, I. (2019). Corralling, planting density, and N fertilizer rate effect on soil properties, weed diversity, and maize yield. *Agroecology and Sustainable Food Systems*, *43*, 243–260. https://doi.org/10.1080/21683565.2018.1516264

Agostinho, F. H., Gravena, R., Alves, P. L. C. A., Salgado, T. P., & Mattos, E. D. (2006). The effect of cultivar on critical periods of weed control in peanuts. *Peanut Science*, *33*, 29–35.

Amanor-Boadu, V., Zereyesus, Y., Ross, K., Ofori-Bah, A., Adams, S., Asiedu-Dartey, J., Gutierrez, E., Hancock, A., Mzyece, A., & Salin, M. (2015). *Agricultural production survey for the northern regions of Ghana: 2013–2014 results*. Final Report.

Ambang, Z., Ndongo, B., Essono, G., Ngoh, J. P., Kosma, P., Chewachong, G. M., & Asanga, A. (2011). Control of leaf spot disease caused by cercospora sp on groundnut ('*Arachis hypogaea*') using methanolic extracts of yellow oleander ('*Thevetia peruviana*') seeds. *Australian Journal of Crop Science*, *5*, 227–232.

Anco, D. J., Thomas, J. S., Jordan, D. L., Shew, B. B., Monfort, W. S., Mehl, H. L., Small, I. M., Wright, D. L., Tillman, B. L., Dufault, N. S., & Hagan, A. K. (2020). Peanut yield loss in the presence of defoliation caused by late or early leaf spot. *Plant Disease*, *104*, 1390–1399. https://doi.org/10.1094/PDIS-11-19-2286-RE

Ansah, T., Sahoo, A. R. N., Kumawat, P. K., & Bhatt, R. S. (2021). In vitro digestibility and methane gas production of fodder from improved cowpea (*Vigna unguiculata* L.) and groundnut (*Arachis hypogaea* L.) varieties. *Scientific African*, *13*, e00897. https://doi.org/10.1016/j.sciaf.2021.e00897

Armstrong, R. A. (2019). Should Pearson's correlation coefficient be avoided?. *Ophthalmic Physiological Optics*, *39*, 316–327.

Bakal, H., Kenetli, A., & Arioglu, H. (2020). The effect of plant density on pod yield and some agronomic characteristics of different growth type peanut varieties (*Arachis hypogaea* L.) grown as a main crop. *Turkish Journal of Field Crops*, *25*, 92–99. https://doi.org/10.17557/tjfc.748671

Bala, H. M. B., Ogunlela, V. B., Tanimu, B., & Kuchinda, N. C. (2011). Response of two groundnut (*Arachis hypogaea* L.) varieties to sowing date and NPK fertilizer rate in a semi-arid environment: Growth and growth attributes. *Asian Journal of Crop Science*, *3*, 141–150.

Berdjour, A., Dugje, I. Y., Dzomeku, I. K., & Abdul Rahman, N. (2020). Maize–soybean intercropping effect on yield productivity, weed control and diversity in northern Ghana. *Weed Biology and Management*, *20*, 69–81. https://doi.org/10.1111/wbm.12198

Bussan, A. J., Burnside, O. C., Orf, J. H., Ristau, E. A., & Puettmann, K. J. (1997). Field evaluation of soybean (Glycine max) genotypes for weed competitiveness. *Weed Science*, *45*(1), 31–37. https://doi.org/10.1017/S0043174500092444

Chandolia, P. C., Dadheech, R. C., Solanki, N. S., & Mundra, S. L. (2010). Weed management in groundnut (*Arachis hypogaea* L.) under varying crop geometry. *Indian Journal of Weed Science*, *42*, 235–237.

Cordeiro, C. F. D. S., Pilon, C., Echer, F. R., Albas, R., Tubbs, R. S., Harris, G. H., & Rosolem, C. A. (2023). Adjusting peanut plant density and potassium fertilization for different production environments. *Agronomy Journal*, *2023*, 1–16. https://doi.org/10.1002/agj2.21271

Dangol, D. R. (1991). Rice field weeds in Chitwan valley, Nepal. Rice science for a better World-International Rice Research Institute. *International Rice Research Newsletter*, *16*, 27–28.

Dapaah, H. K., Mohammed, I., & Awuah, R. T. (2014). Phenological development and yield of three groundnut varieties as influenced by plant density in a forest-savanna transition zone. *International Journal of Agricultural Research*, *9*, 87–98.

Daubenmire, R. F. (1959). A canopy-coverage method of vegetational analysis. *Northwest Science*, *33*, 43–64.

Dias-Filho, M. B. (1996). Germination and emergence of *Stachytarpheta cayennensis* and *Ipomoea asarifolia*. *Planta Daninha*, *14*, 118–126. https://doi.org/10.1590/S0100-83581996000200005

Dzomeku, I. K., Abudulai, M., Brandenburg, R. L., & Jordan, D. L. (2009). Survey of weeds and management practices in Peanut (Arachis hypogaea L.) in the savanna ecology of Ghana[1]. *Peanut Science*, *36*(2), 165–173. https://doi.org/10.3146/PS08-009.1

Everman, W. J., Clewis, S. B., Thomas, W. E., Burke, I. C., & Wilcut, J. W. (2008). Critical period of weed interference in peanut. *Weed Technology*, *22*, 63–67. https://doi.org/10.1614/WT-07-052.1

Farrel, J. K., Bailey, J. E., & Mills, W. R. (1967). The effects of time of planting, spacing and fungicide on Cercospora leaf spots on groundnut in Malawi, Rhodesia and Zambia. *Malawi Journal of Agricultural Research*, *5*, 241–247.

Gaikpa, D. S., Akromah, R., Asibuo, J. Y., Appiah-Kubi, Z., & Nyadanu, D. (2015). Evaluation of yield and yield components of groundnut genotypes under Cercospora leaf spots disease pressure. *International Journal of Agronomy and Agricultural Research*, *7*, 66–75.

Hill, M. O. (1973). Diversity and evenness: A unifying notation and its consequences. *Ecology*, *54*, 427–432. https://doi.org/10.2307/1934352

Islam, M. S., Akhter, M. M., Haque, M. M., & Saneokaoka, H. (2011). Influence of plant population and weed management periods on crop-weed competition of groundnut. *Journal of Sher-e-Bangla Agricultural University*, *5*, 26–34.

Jat, R. S., Meena, H. N., Singh, A. L., Surya, J. N., & Misra, J. B. (2011). Weed management in groundnut (*Arachis hypogaea* L.) in India—A review. *Agricultural Reviews*, *32*, 155–171.

Johnson, W. C., III, Prostko, E. P., & Mullinix, B. G., Jr. (2005). Improving the management of dicot weeds in peanut with narrow row spacings and residual herbicides. *Agronomy Journal*, *97*, 85–88. https://doi.org/10.2134/agronj2005.0085a

Jolly, C. M., Awuah, R. T., Fialor, S. C., Agyemang, K. O., Kagochi, J. M., & Binns, A. D. (2008). Groundnut consumption frequency in Ghana. *International Journal of Consumer Studies*, *32*, 675–686. https://doi.org/10.1111/j.1470-6431.2008.00697.x

Kamara, A. Y., Ekeleme, F., Kwari, J. D., Omoigui, L. O., & Chikoye, D. (2011). Phosphorus effects on growth and yield of groundnut varieties in the tropical savannas of northeast Nigeria. *Journal of Tropical Agriculture*, *49*, 25–30.

Kankam, F., Akpatsu, I. B., & Tengey, T. K. (2022). Leaf spot disease of groundnut: A review of existing research on management strategies. *Cogent Food & Agriculture*, *8*(1), 2118650. https://doi.org/10.1080/23311932.2022.2118650

Kharel, P., Devkota, P., Macdonald, G. E., Tillman, B. L., & Mulvaney, M. J. (2022). Influence of planting date, row spacing, and reduced herbicide inputs on peanut canopy and sicklepod growth. *Agronomy Journal*, *114*, 717–726. https://doi.org/10.1002/agj2.20946

Kokalis-Burelle, N., Porter, D. M., Rodriguez-Kabana, R., Smith, D. H., & Subrahmanyam, P. (1997). *Compendium of peanut diseases* (second ed.). Phytopathological Society.

Kumar, N. S. (2009). Effect of plant density and weed management practices on production potential of groundnut (*Arachis hypogaea* L.). *Indian Journal of Agricultural Research*, *43*, 57–60.

Kumar, V., & Thirumalaisamy, P. P. (2016). *Diseases of groundnut*. Indian Phytopathological Society, Today and Tomorrow's Printers and Publishers.

Larbi, A., Dung, D. D., Olorunju, P. E., Smith, J. W., Tanko, R. J., Muhammad, I. R., & Adekunle, I. O. (1999). Groundnut (*Arachis hypogaea*) for food and fodder in crop-livestock systems: Forage and seed yields, chemical composition and rumen degradation of leaf and stem fractions of 38 cultivars. *Animal Feed Science and Technology*, *77*, 33–47. https://doi.org/10.1016/S0377-8401(98)00238-7

MoFA (Ministry of Food and Agriculture). (2021). Agriculture in Ghana: Facts and figures (2020). Statistics, Research and Information Directorate (SIRD), Accra.

Naab, J. B., Boote, K. J., Prasad, P. V. V., Seini, S. S., & Jones, J. W. (2009). Influence of fungicide and sowing density on the growth and yield of two groundnut cultivars. *The Journal of Agricultural Science*, *147*, 179–191. https://doi.org/10.1017/S0021859608008290

Naab, J. B., Seini, S. S., Gyasi, K. O., Mahama, G. Y., Prasad, P. V. V., Boote, K. J., & Jones, J. W. (2009). Groundnut yield response and economic benefits of fungicide and phosphorus application in farmer-managed trials in northern Ghana. *Experimental Agriculture*, *45*, 385–399. https://doi.org/10.1017/S0014479709990081

Pande, S., & Rao, J. N. (2002). Effect of plant population densities on the severity of late leaf spot and rust of groundnut. *Plant Pathology Journal*, *18*, 271–278.

Prasad, P. V. V., Kakani, V. G., & Upadhyaya, H. D. (2009). Growth and production of groundnut, in soils, plant growth and crop production. In H. V. Willy (Ed.), *Encyclopedia of life support systems (EOLSS), developed under the auspices of the UNESCO* (pp. 1–26). Eolss Publishers.

Priya, T. B., Subramanyam, D., & Sumathi, V. (2015). Weed dynamics and yield of groundnut as influenced by varieties and plant population. *Indian Journal of Weed Science*, *47*(1), 75–77.

Sanginga, N. (2003). Role of biological nitrogen fixation in legume-based cropping systems; a case study of West Africa farming systems. *Plant and Soil*, *252*, 25–39. https://doi.org/10.1023/A:1024192604607

SAS Institute. (2015). *Base SAS 9.4 procedures guide*. SAS Institute.

Tarawali, A. R., & Quee, D. D. (2014). Performance of groundnut (*Arachis hypogaea* L) varieties in two agro-ecologies of Sierra Leone. *African Journal of Agricultural Research*, *9*, 1442–1448.

Tetteh, F. M., Larbi, A., Nketia, K. A., Senaya, J. N., Hoeschle-Zeledon, I., & Abdul Rahman, N. (2016). Suitability of soils for cereal cropping in Northern Ghana. Evaluation and recommendations. International Institute of Tropical Agriculture (IITA).

Tillman, B. L., Gorbet, D. W., Culbreath, A. K., & Todd, J. W. (2006). Response of peanut cultivars to seeding density and row patterns. *Crop Management*, *5*, 1–7. https://doi.org/10.1094/CM-2006-0711-01-RS

Tsigbey, F. K., Brandenburg, R. L., & Clottey, V. A. (2003). Peanut production methods in northern Ghana and some disease perspectives. *World Geography of the Peanut Knowledge Base Website*, 1–9. http://crsps.net/resource/peanut-production-methods-in-northern-ghana-and-some-disease-perspectives/. Accessed July, 2023

Walker, S. R., & Evenson, J. P. (1985). Biology of *Commelina benghalensis* L. in south-eastern Queensland. 2. Seed dormancy, germination and emergence. *Weed Research*, *25*(4), 245–250. https://doi.org/10.1111/j.1365-3180.1985.tb00641.x

Yayock, J. Y. (1981). Effects of population density and leaf-spots control on yield of groundnuts (*Arachis hypogaea* L.) in Nigeria. *Samaru Journal of Agricultural Research*, *1*, 3–10.

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Additional supporting information can be found online in the Supporting Information section at the end of this article.

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