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Tillage and intercropping effect on growth and yield of groundnut in maize/groundnut cropping system

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ABSTRACT

Due to high population pressure / human activities competing for agriculture land, the need to maximize productivity of available land has become necessary; this has not been achievable in the tropics with monoculture systems where single harvest per season is the practice. Thus, this study evaluates crop combination and tillage practice on yield and yield components of groundnut in mixture with maize. The trial was conducted in the rainy seasons of 2020 and 2021, at the Kogi State University Students' Research and Demonstration Farm; Latitude 70 301 and Longitude 70 091 E in the Southern Guinea Savannah agro-ecological zone of Nigeria. Treatment consisted of three tillage practices (main plot factor) and five crop combinations (subplot factor) assigned to a 3 x 5 Factorial experiment replicated four times. Sole cropped groundnut performed better than the intercrops regarding yield and yield related parameters. Better haulm yields were obtained in sole cropped plots (711.11 kg/ha and 637.04 kg/ha, respectively in 2020 and 2021 seasons; better pod yields: 1,532 kg/ha and 1,367 kg/ha, respectively in 2020 and 2021 seasons, better Harvest Index (53.26% and 36.78%, respectively in 2020, 2021 cropping seasons). The treatment recorded the best 100-seed weight in both seasons: 47.83, and 48.32g, respectively in 2020, 2021 cropping seasons. It also gave the best shelling percentage: 61.00% and 79.42%, respectively in 2020, 2021 cropping seasons. Relative to LER, among crop combination, the highest LERs were observed when one row of maize was intercropped with one row of groundnut (1.38 and 1.32, respectively in 2020 and 2021 cropping seasons) with the least LER observed when two rows of maize were intercropped with one row of groundnut (1.28 and 1.19, respectively in 2020 and 2021 seasons). Among the tillage practice, zero tillage gave the highest LER (1.28 and 1.42, respectively in 2020 and 2021 seasons) with planting on ridges giving the least LER (1.06 and 1.38, respectively in 2020 and 2021 cropping seasons). Since the highest LER was observed when one row of maize was intercropped with one row of groundnut, this level of crop combination is recommended for the study area.

Keywords: Canopy height, leaf number, haulm yield / ha, pod yield / ha, harvest index and shelling percentage

INTRODUCTION

Due to high population pressure couple with other human activities competing with agriculture for available land, the need to maximize land productivity in the tropics is becoming increasingly necessary (Steiner, 1991; Oyewole et al., 2023a; Oyewole et al., 2023b). Maximization of land productivity has not been achievable with monoculture systems where single harvest per season is the practice; considering that gains in production per unit area under these monoculture systems have not been impressive in the tropical environment (IITA, 1990; Oyewole, 2004). Thus, intercropping of two or more crops especially the family Poaceae with Fabaceae is popular in many of these countries because yields are often higher than pure cropping systems (Lithourgidis et al., 2006; Oyewole et al., 2023a; Oyewole et al., 2023b).

Intercropping maize or any other cereal crop with legumes is one of the common cropping systems in Africa that is offering farmers the opportunity to engage nature's principle of diversity (Sullivan, 2003; Oyewole, 2004; Oyewole, et al., 2005). Cereal - legume intercrops have been reported to be more productive and remunerative compared to sole cropping (Li et al., 2003; Lithourgidis et al., 2006; Oyewole el al., 2005). Cereal - legume intercrop systems are able to lessen amount of nutrients taken from the soil in comparison to a maize mono crop (Tsubo et al., 2005). While Kamanga et al. (2010) observed that maize - legume intercrops are more productive and less risky compared with their individual mono systems.

Generally, intercropping can be described as the planting of two or more crops simultaneously on the same piece of land during the growing season (Palaniappan, 2000; Oyewole, 2004; Oyewole, et al., 2005). The main types of intercropping systems include strip row, relay and mixed row (Dwomon, and Quainoo (2012). Spatial arrangement of crops is another type of intercropping where two or more crops are growing on separate rows or alternating rows on the same piece of land. In this arrangement, crops involved compete for growth resources such as light, water, carbon dioxide and nutrients. However, several advantages have been documented for the use of spatial arrangements in lieu of sole cropping (Steiner, 1991; Oyewole, 2004; Oyewole, et al., 2005). Higher yields have been reported when competition between two species of the mixtures have lower competition than within the same species (Vandermer, 1990; Antenyi, 2021). Shading by heavier leaf canopy in an intercropping system reduces soil temperature and moisture loss, which favour multiplication and growth of some soil microorganisms (Petersen, 1994). In spite of these merits, some of the disadvantages associated with intercropping in mechanized farming is that overall cost per unit production may be higher due to reduce efficiency in planting, weeding and harvesting (Steiner, 1991; Oyewole, 2004; Dwomon, and Quainoo, 2012; Antenyi, 2021).

Intercropping maize with legumes (groundnut, cowpea, Bambara nut, pigeon pea) is one of the common cropping systems in Africa which is currently receiving global attention because of its prime importance in world production. Sullivan (2003) observed that it offers crop growers the opportunity to engage nature's principle of diversity in crop production. Cereal-legume intercropping has been reported to be more productive and remunerative compared with sole cropping (Li et al., 2003; Lithourgidis et al., 2006). As well as playing important roles in food production in both developed and developing countries, especially in situation of restricted water resources (Li et al., 2003). In addition, maize-legume intercropping systems are able to lessen amount of nutrients taken from the soil in comparison with maize monocrop (Tsubo, et al., 2005).

Corn generally grows best in deep, well drained soils, although with irrigation good yields have been obtained on a wide variety of soil types (David et al., 2017). Crop management practices such as tillage, strive to maximize economic yield, but responses to these practices vary across environments (Fageria et al., 2006).

Tillage may be described as the practice of modifying the state of the soil in order to provide conditions favorable for crop growth (David et al., 2017). Soil tillage is an important agricultural activity because of its impact on crop production, soil properties and environment (Boone and Veen, 1994). Tillage is used for a variety of purpose, including preparation of seedbeds, seed placement, reduction of soil compaction, incorporating crop residues and weed control (Liu et al., 2008).

The task of tillage is to prepare soils for productive use or to place the soil in the best physical condition for the crop to grow (Husnjack et al., 2002). To be sure of normal plant growth, the soil must be in such condition that roots can have enough air, water and nutrients (Husnjack et al., 2002). There are two major tillage systems namely conventional tillage and conservation tillage (Srivastava et al., 2006). The reference system for tillage is the conventional tillage system, which is based on a high intensity of soil engagement and inversion of the soil. Conventional tillage is used to prepare the seedbed (improving seed-soil contact), facilitating regular, unvarying early plant emergence (Josa et al., 2010). Conservation tillage is defined to be any tillage or sowing system which leaves at least 30% of the field covered with crop residue after sowing has been completed. In such soils, erosion is reduced by at least 50% as compared with bare, fallow soils (Karayel, 2009).

David et al (2017) in their document: Field Corn Production Guide, observed that a good soil management program: protects the soil from water and wind erosion; provides a weed-free seedbed for planting; disrupts hardpans or compacted layers that may limit root development; and allows maintenance or even an increase of organic matter. Stating that water erosion is a significant problem on all soil types that have been tilled and have no cover crops during high rainfall. While the authors observed that wind erosion can be a problem on sandy soils.

Furthermore, David et al (2017) reported that Strip tillage leaves various amounts of previous crop residue or cover crop on the surface, improving water infiltration and reducing soil erosion. Adding that, Strip-tilling into a previous crop residue or cover crop is effective as long as the seedbed is not rutted from the previous harvesting operation or washed out by heavy rains. The authors added that, it is desirable to kill cover crops several weeks ahead of planting to reduce competition from the cover crop.

In conclusion, compacted layer, common in un-tilled soils, restricts root growth and water and nutrient uptake by crops. Subsoiling enables corn to develop deeper root systems that make better use of subsoil moisture and improves the chances of recovering nutrients as they move through the soil (David et. al., 2017). The authors reported that In-row subsoiling increased corn yields over 50% on soils where no or limited irrigation occurred.

Groundnut is grown mainly for its seed oil content, food and animal feed. It plays an important role in the dietary requirements of resource poor women and children because of its high contents of protein and carbohydrate; containing 48-50% oil, 24-26% protein, and 10-20% carbohydrate (Obi et al., 2008). Groundnut kernels are consumed directly as raw, roasted or boiled kernels while the oil extracted from the kernel is used as culinary oil. The haulm is also an important by - products that can be used to supply feed to livestock. While Attah and Oyewole (2013) observed that over the years, maize has become an important crop, taking over acreages from traditional crops such as millet and sorghum. FAO (2012) stated that in the past few decades, maize production has increased tremendously in the tropical rainforest. The crop serves as a staple food for some more than 300 million people in less developed countries such as Africa and Latin America; accounting for daily total calories of about 15–20% in the diets of 20 of these less developed countries (Adetimirin et al., 2008; Ologunde and Ogunlela, 1984). Maize has been commonly intercropped with groundnut in the farming systems of the study area, thus the need to evaluate effect of tillage practice on growth, yield and yield components of groundnut in a maize / groundnut intercrop system. The main objective of the study was to evaluate effect of crop combination and tillage practice on, yield and yield components of groundnut in a maize / groundnut intercrop. As well as determine interactions between crop combination and tillage practice on growth, yield and yield components of groundnut in mixture. To achieve the objectives above, the following null hypotheses were formulated: 1) That there will be no effect of crop combination on the growth, yield and yield components of groundnut in mixture, 2) tillage practice will have no significant effect on the growth, yield and yield components of groundnut in mixture, and 3) there will be no significant interactions between crop combination and tillage practice on the growth, yield and yield components of groundnut in mixture.

MATERIALS AND METHODS

The experiment was conducted in the rainy season of 2020 and 2021 at the Kogi State University Anyigba Students' Research and Demonstration Farm; Latitude 70 301 and Longitude 70 091 E in the Southern Guinea Savannah agro-ecological zone of Nigeria. The experimental site has been consistently under cultivation for over a decade, basically for the growing of rainfed maize, cassava, soybean or cowpea, with maize being the prominent crop. The common practice on the experimental site was to grow maize alongside groundnut or cassava early in the rain (March / April) as first crop to be replaced by cowpea, soybean or Bambara sometime in June/July as second crop. Conventional tillage as well as application of mineral fertilizers has been a routine practice on the site for decades. The soil is predominantly sandy to sandy loam (Appendix I). Temperatures show some variations throughout the year, with mean monthly temperatures varying between 15.1 $^{\circ}$C and 36.2 $^{\circ}$C.

Treatment investigated consisted of three tillage practice methods (planting on ridge; planting on flat land; and zero tillage), which were apportioned as main plot factor and five crop combinations (Sole Maize; Sole Groundnut; Two rows of maize to one row of groundnut; Two rows of groundnut to one row of maize; One row of maize to one row of groundnut) apportioned to the subplot factor in a 3 x 5 Factorial experiment with four replications.

For the tillage practice involving planting seeds on the flat, the land was ploughed, harrowed and made into flat beds (3 x 4.5 m), while for those crops sown on ridges, the experimental area was ploughed, harrowed and ridged 75cm apart; for the zero tillage, these conventional tillage practices outlined above, were not done before seed sowing.

Subplot size measuring 3 m x 4.5 m (sixty subplots) were used for the experiment; each plot consisted of 6 rows of crop stands, spaced either 25 cm apart for maize or 23 cm apart for groundnut. For maize stands, which were spaced 25 cm x 75 cm, sole crop plots had a total of 72 plant stands, while for groundnut, which were spaced 23 cm x 75 cm, there were 78 stands of groundnut in sole plots. In a plot consisting of one row of maize to one row of groundnut, there were three rows each of maize and groundnut, with a total population of 36 maize stands to 39 groundnut stands. For two rows of maize to one row of groundnut, there were 48 maize stands to

26 groundnut stands. While for two rows of groundnut to one row of maize, there were 24 maize stands to 52 groundnut stands.

One improved variety of maize (TZESR) and one local variety of groundnuts (Angba-chido) obtained from IITA – Ibadan and Agricultural Development Project (ADP) Anyigba, Kogi state, respectively were used in the experiment. Row replacement method was employed (Oyewole, 2004) in seeding the groundnut rows among the maize rows; moving from sole cropped plots of six rows of maize, which were then gradually replaced with rows of groundnut stands until attaining sole groundnut plots. While the groundnut stands were seeded 23 cm x 75 cm, the maize stands were seeded 25 cm x 75 cm. Two seeds of groundnut as well as maize were planted per hole, which were thinned to one seedling per stand at two weeks after planting (2 WAP).

NPK 15:15:15 (compound fertilizer) was applied to all the plots as basal application (45 kg N/ha, 45 kg P_2O_5 and 45 kg K_2O/ha) and top dressed with Urea (46% N) at 6 WAP at the rate of 75 kg N/ha. Thus, total nutrient application was 120 kg N/ha, 45 kg P_2O_5 and 45 kg K_2O/ha.

Percentage seedling emergence was determined at two weeks after planting (2 WAP). For determination of plant growth, development and yield parameters, ten plants were randomly selected and tagged from the net plot (2.5 m x 4 m) for canopy height determination (at 3, 5, 7 and 9 WAP); days to first flowering, pod yield/ha, shelling percentage, haulm yield (kg/ ha), 100-seed weight, seeds per pod as well as harvest index (HI %) in line with Donald (1963); Oyewole (2010); Oyewole (2011); Oyewole et al. (2005); Oyewole et al. (2015a & 2015b).

The advantages of maize-groundnut intercropping were evaluated using the LER. Land equivalent ratios (LER) was used to quantify the land use efficiency of the intercropping system, which is the relative land area of a sole crop required to produce the yield achieved in intercropping (Willy and Osiru, 1972). Where LER> 1, the intercropping favours the growth and yield of the mixture, but in contrast, where LER< 1, there is no intercropping advantage (Zhang et al., 2011). LER of the sole crop was taken as unity. LER was calculated as:

$$\text{LER groundnut} = \frac{\text{Yield of Groundnut in the intercrop}}{\text{Yield of groundnut in sole crop}}$$

Determination of Growth Parameters

Canopy height (cm)

Ten plants were randomly selected and tagged from the net plot for height determination and recorded as the average of ten plants measured (cm). Canopy height was a measure of the plant from the surface of the soil to the apex of the plant canopy; a parameter taken at two-week interval, with the aid of a meter rule.

Number of leaves per plant

From the ten tagged plants, the total number of leaves were determined by simple count and recorded as the mean of ten sampled plants.

Yield Parameters

Pod yield / ha

Plants from the net plots were separately harvested and the pods stripped, sun-dried for fourteen days to constant weight before been measured on a Metler Toledo electric weighing balance. Data obtained were extrapolated to pod yield / ha (t/ha).

kShelling percentage

Shelling percentage expressed as ratios of seed weight relative to pod weight in percentage. To obtain this parameter, two batches of fifty pods were weighed per plot, hand shelled and the seeds obtained were weighed. The shelling percentage was calculated as shown below:

$$\text{Shelling (\%)} = \frac{\text{Seed weight}}{\text{Pod weigh}} \times 100$$

Harvest index (HI%)

This is the ratio of total economic yield to the total plant dry matter or biomass produced by the system at harvest. HI was determined using the relationship expressed below:

$$\text{HI} = \frac{\text{Seed weight}}{\text{Total dry matter at harvest}} \times 100$$

Haulm yield (kg/ ha)

After stripping the pods from the harvested plants within the net plot, the entire crop vegetative matter was bulked together / net plot sundried for two weeks, the total weight was determined using a weighing scale and extrapolated to t/ha.

Number of seeds per pod

To obtain this parameter, fifty pods was randomly sampled, hand-shelled, and the seeds was counted. The total number of seeds was divided by fifty to obtain average seeds number per pod.

100-seed weight (g)

From the hand shelled seeds obtained from each net plot, a hundred seed sample was drawn and weighed using an electronic scale.

Analysis of Data

Data collected were subjected to Analysis of Variance (ANOVA) as described for Factorial Experiment (Statistical Analysis System (SAS), 1998) and means found to be statistically significant at 5% probability were separated using LSD.

RESULTS AND DISCUSSION

Chemical and Physical properties of the experimental Soil

The pre-physical and chemical properties of the experimental site is shown in Appendix I. The result showed that the soil of the experimental area was predominantly sandy on the surface (0 – 15 cm) tending towards sandy loam with depth of profile (15 – 30 cm). The soil is acidic revealing a pH of 5.70 and 5.20 in H2O (0 – 15 cm depth), respectively in 2020 and 2021 cropping seasons. The organic matter contents and total nitrogen were low with values of 0.36 (0 – 15 cm depth) and 0.40 Cmol/kg (0 – 30 cm depth) in 2020 and 0.18 (0 – 15 cm depth) and 0.16 Cmol/kg (0 – 30 cm depth) in 2021. Available P value were 4.29 (0 – 15 cm) and 3.07 mg/kg-1 (0 – 30 cm) in 2020 and 4.05 and 3.64 mg/kg-1 (0 – 15 cm and 15 – 30 cm, respectively) in 2021. The exchangeable cations (Ca, Mg and K) were equally low in status. Texturally, the soil of the experimental site was classified as sandy loam.

Groundnut canopy height

Throughout the period of data collection, no significant (p≥ 0.05) effect of tillage system studied were observed on groundnut canopy heights in both trials: 2020 and 2021 cropping seasons; an indication that, tillage operations investigated do not impact positively groundnut canopy height. Despite this observation, in 2020 cropping season, the tallest canopy heights were consistently observed when groundnuts were sown on flat beds: 3.99 ± 0.40 cm (3 WAP), 14.60 ± 1.10 cm (5 WAP), 22.35 ± 1.00 cm (7WAP) and 24.12 ± 1.20 cm (9 WAP), while sowing groundnut on ridges gave the shortest average canopy heights: 23.00 ± 1.70 cm in 2020 and 25.94 ± 2.70 cm in 2021 cropping season. It should be observed that the best crop heights in maize (Table 2) were observed in the maize crops sown on the flat bed within this period. Thus, taller maize crops may have influenced corresponding height responses in the groundnut stands. In 2021 cropping season better height performances were observed in the zero tillage: 6.62 ± 1.20 cm (3WAP), 10.97 ± 1.10 cm (5WAP), 22.75 ± 1.10 cm (7WAP) and 27.33 ± 2.20 cm (9WAP). Better height performances were generally observed in 2021 cropping season compared with 2020 season. This could be the result of better climatic effects, particularly rainfall and temperatures.

Analyzed data showed that crop combination did not significantly (p≥ 0.05) influence groundnut canopy height at 3 and 5 WAP (Week after planting) during 2020 cropping season, but did affect this parameter at 7 and 9 WAP (Table 1). Expectedly, at 7 and 9 WAP effects of both intra and inter-competition for solar radiation among the component crops were well pronounced (Oyewole et al., 2024) to cause an observe canopy height variations between the intercrops when compared with the sole cropped groundnut plots. However, among the intercrops there were no such significant variations (p≥ 0.05) in the observed canopy outcomes; an indication that both intra and interspecific competitions among the associating crops were not pronounced enough to cause any significant effect on the associating groundnut canopy heights. This may be due to rather insignificant height variations among the associating maize stands in the intercrop combinations; as no statistical significance were observed among the intercrop maize stands (Table 2). However, as the maize population within the crop mixture increases, groundnut canopy heights were observed to increase in both years, though not statistically significant.

In the 2021 cropping season, there was an early effect of intercrop combination on canopy height, which was consistently maintained all through the period of data collection at 3, 5, 7 and 9 WAP (Table 1). At 9 WAP sole groundnut plots gave the tallest average crop canopy height (34.04 ± 1.50 cm), which was significantly (P≤ 0.05) different from the intercrop combinations, with intercropping at 2 rows of maize to 1 row of groundnut giving the shortest average canopy height (27.10 ± 2.70 cm) within the same period. The observation is an indication that intraspecific competition played a larger role on canopy height rather than interspecific completion for solar radiation. These observations contradict expectations (Oyewole, 2004; Oyewole, 2005); considering that intercropping at 2 rows of maize to 1 row groundnut had the highest maize population in the intercrops 48 maize stands to 26 groundnut stands, in addition, the tallest maize stands were witnessed when maize and groundnut were intercropped at 2 rows of maize to 1 row groundnut (129.44 ± 3.11 and 156.46 ± 2.56, respectively in 2020 and 2021) at 9 WAP (Table 2). All things being equal, it should be expected that the associating groundnut stands in an attempt to escape the smothering effect of the associating maize in these mixtures should lead to leaf etiolation, thus producing crops with taller canopy height (Oyewole, 2004; Oyewole, 2005), however intercropping at 1 row of maize to 1 row of groundnut consistently did better than other crop combinations, giving the tallest crop canopy heights at the termination of the trial (28.18 ± 1.10 cm) in 2020 cropping season and (32.19 ± 3.00 cm) in 2021 cropping season. It should, however be noted there were no significant different in the observed groundnut canopy height among the intercrops (Table 1), an indication that groundnut crop will lend itself to intercropping, without significant adverse effect on canopy height.

No significant ($p \geq 0.05$) interactions were recorded between tillage practice and intercropping combination on groundnut canopy height at 3, 5, 7 and 9 WAP in 2020 and 2021 cropping seasons. This means the effects of tillage and intercropping combination on groundnut canopy heights are independent of each other. For the farmers, this implies that they can choose the best tillage method and the intercropping combination separately to optimize canopy height formation in groundnut.

Table 1 Effect of crop combination, tillage practice and their interactions on groundnut canopy height (cm) in Anyigba in 2020 and 2021 growing season

Treatment	Groundnut canopy height (cm)							
	2020 cropping season				2021 cropping season			
	3 WAP	5 WAP	7 WAP	9 WAP	3 WAP	5 WAP	7 WAP	9 WAP
Crop combination (P)								
Sole groundnut	4.71 ± 1.10	17.02 ± 1.10	30.47 ± 1.10^{a}	34.04 ± 1.50^{a}	9.76 ± 2.00^{a}	15.48 ± 2.00^{a}	31.83 ± 2.02^{a}	38.00 ± 3.00^{a}
2 maize:1 g/nutk	4.22 ± 1.90	16.14 ± 2.00	26.13 ± 2.50^{b}	27.10 ± 2.70^{b}	7.55 ± 1.70^{b}	12.62 ± 1.90^{b}	25.25 ± 2.00^{b}	31.23 ± 2.70^{b}
2 g/nut:1 maize	4.81 ± 1.01	17.67 ± 1.50	26.71 ± 1.10^{b}	27.95 ± 1.50^{b}	7.51 ± 1.50^{b}	12.77 ± 1.20^{b}	25.95 ± 1.60^{b}	31.40 ± 2.00^{b}
1 maize:1 g/nut	4.44 ± 1.00	17.64 ± 1.80	26.15 ± 1.30^{b}	28.18 ± 1.10^{b}	7.81 ± 1.70^{b}	13.19 ± 1.80^{b}	26.23 ± 2.20^{b}	32.19 ± 3.00^{b}
LSD (0.05)	0.805^{ns}	2.161^{ns}	2.603*	2.603*	0.584*	0.981*	1.391*	1.592*
Tillage practice (T)								
Ridge	3.50 ± 0.60^{a}	12.98 ± 1.00	21.75 ± 1.60	23.00 ± 1.70	6.56 ± 1.65	10.68 ± 1.60	21.39 ± 1.50	25.94 ± 2.70
Flat	3.99 ± 0.40^{a}	14.60 ± 1.10	22.35 ± 1.00	24.12 ± 1.20	6.40 ± 1.10	10.78 ± 1.10	21.42 ± 1.10	26.43 ± 2.10
Zero tillage	3.42 ± 0.30^{a}	13.52 ± 1.00	21.58 ± 1.20	23.46 ± 1.20	6.62 ± 1.20	10.97 ± 1.10	22.75 ± 1.10	27.33 ± 2.20
LSD (0.05)	0.622^{ns}	1.671^{ns}	2.024^{ns}	2.012^{ns}	0.452^{ns}	0.761^{ns}	1.081^{ns}	1.232^{ns}
Interaction								
P × T	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
CV (%)	26.6	19.1	14.4	13.4	10.7	11.1	7.7	7.3

Note: LSD* significant at 5%; LSD ns: Not significant at 5% level of probability; Means followed by the same letter(s) are not statistically different at 5% level of probability

Table 2 Effect of crop combination, tillage practice and their interactions on average heights (cm) of maize in Anyigba, Kogi State, Nigeria in 2020 and 2021 cropping seasons

Treatment	Maize average height (cm)							
	2020 cropping season				2021 cropping season			
	3 WAP	5 WAP	7 WAP	9 WAP	3 WAP	5 WAP	7 WAP	9 WAP
Crop combination								
Sole maize	18.76 ± 1.06^{ab}	51.90 ± 2.01^{a}	108.20 ± 4.67^{a}	144.64 ± 4.88^{a}	30.67 ± 2.42^{a}	48.59 ± 3.67^{a}	96.29 ± 4.00^{a}	170.90 ± 3.00^{a}
2 maize:1 g/nut	19.98 ± 1.04^{ab}	44.17 ± 1.49^{a}	86.61 ± 2.45^{b}	129.44 ± 3.11^{bc}	25.28 ± 2.23^{b}	38.08 ± 3.23^{b}	80.98 ± 3.94^{b}	156.46 ± 2.56^{b}
2 g/nut:1 maize	16.81 ± 1.02^{b}	38.07 ± 1.34^{b}	77.25 ± 2.33^{b}	121.35 ± 3.00^{c}	26.02 ± 2.00^{b}	38.97 ± 2.89^{b}	80.17 ± 3.52^{b}	150.07 ± 2.11^{b}
1 maize:1 g/nut	20.42 ± 1.04^{a}	41.57 ± 1.32^{a}	81.82 ± 2.16^{b}	128.09 ± 3.21^{c}	25.77 ± 1.78^{b}	38.90 ± 2.11^{b}	79.84 ± 2.65^{b}	153.69 ± 2.00^{b}
LSD (0.05)	2.621*	7.899*	10.726*	15.717*	1.531*	3.513*	6.418*	12.827*
Tillage practice (T)								
Ridge	14.56 ± 1.03^{b}	32.11 ± 2.00	70.89 ± 4.22^{b}	104.62 ± 3.87	26.61 ± 1.45	39.69 ± 2.56	82.20 ± 3.87	154.70 ± 2.98
Flat	17.20 ± 1.05^{a}	36.00 ± 2.03	78.08 ± 3.55^{a}	110.72 ± 3.86	27.27 ± 1.34	41.45 ± 2.41	86.65 ± 3,81	161.73 ± 2.18
Zero tillage	13.83 ± 1.02^{b}	31.31 ± 2.01	63.36 ± 3.33^{c}	98.77 ± 2.12	26.92 ± 1.22	42.27 ± 2.33	84.12 ± 3.00	156.91 ± 2.01
LSD (0.05)	1.033*	5.117^{ns}	5.305*	6.178^{ns}	2.148^{ns}	3.722^{ns}	2.972^{ns}	9.931^{ns}
Interaction								
P × T	*	*	*	*	*	*	*	*
CV (%)	20.9	28.9	18.4	18.2	8.6	13.0	11.5	12.3

Note: LSD* significant at 5%; LSD ns: Not significant at 5%; Means followed by the same letter(s) are not statistically different at 5% level of probability

Leaf number in groundnut

No significant (p≥0.05) effects of tillage were observed on average numbers of leaves in the groundnut crops throughout the period of data collection: 3, 5, 7 and 9 WAP (Table 3). Except where tillage can impact root penetration into the soil thus encouraging water uptake with the potential of better vegetative development, planting groundnut on flat beds, ridges or zero tillage may not impact positively leaf formation in groundnut stands. It is important to note that leaves are essential in photosynthesis and subsequently yield formation.

However, numbers of leaves in the groundnut stands responded significantly (P≤ 0.05) to intercrop combination at 7 and 9 WAP in 2020 cropping season and at 3, 5, 7 and 9 WAP in 2021 cropping season (Table 3). The highest average number of leaves, 835.30 ± 32.00 was observed in sole groundnut plots, while among the intercrops, 1 row of maize: 1 row groundnut mixture gave the highest leaf number, 639.61 ± 29.00 in 2020 cropping season, at the end of the trial. While in 2021 cropping season, crop mixture at 2 maize rows: 1 groundnut row gave the highest average number of leaves, 3,246.30 ± 20.00, while the least average number of leaves, 1,853.41 ± 30.00 was in 1 row of maize: 1 row of groundnut intercrop mixture. Noting the Sink-Source relationship, it is expected that the higher the number of leaves the higher the expected crop yield, observing all other limiting factors, such leaf architectures, among other factors that may limit leaves photosynthetic abilities.

No observed significant (p≥0.05) interactions were recorded between crop combination and tillage practice on number of leaves in groundnut throughout the period of data collection. As observed in canopy height, this means the effects of tillage and intercropping combination on groundnut leaf formation are independent of each other. For the farmers, this also implies that they can choose the best tillage method and the intercropping combination separately to optimize canopy formation in groundnut.

Table 3 Effect of crop combination, tillage practice and their interactions on number of leaves in groundnut in 2020 and 2021 cropping seasons

Treatment	Number of leaves (groundnut)							
	2020 cropping season				2021 cropping season			
	3 WAP	5 WAP	7 WAP	9 WAP	3 WAP	5 WAP	7 WAP	9 WAP
Crop combination (P)								
Sole groundnut	46.21 ± 2.00	274.56 ± 21.00	604.53 ± 31.00[a]	835.30 ± 32.00[a]	212.44 ± 30.00[a]	299.39 ± 30.00[a]	1,414.56 ± 31.0(	2,110.47 ± 30.00[b]
2 maize:1 g/nut	43.91 ± 3.00	230.66 ± 20.00	395.41 ± 21.00[b]	428.16 ± 22.00[c]	178.34 ± 20.00[b]	233.77 ± 20.00[c]	1,023.47 ± 20.0(	3,246.30 ± 20.00[a]
2 g/nut:1 maize	47.47 ± 2.00	281.00 ± 31.00	435.26 ± 32.00[b]	599.07 ± 33.00[b]	181.87 ± 30.00[b]	238.78 ± 30.00[c]	1,112.83 ± 30.0(	1,854.55 ± 30.00[c]
1 maize:1 g/nut	44.94 ± 2.00	267.39 ± 23.00	446.85 ± 23.00[b]	639.61 ± 29.00[b]	174.05 ± 30.00[b]	250.69 ± 30.00[b]	1,079.05 ± 30.0(	1,853.41 ± 30.00[c]
LSD (0.05)	4.641[ns]	44.964[ns]	60.111**	105.578**	10.502**	11.351**	103.410**	175.671*
Tillage practice (T)								
Ridge	37.26 ± 2.00	210.21 ± 20.00	364.78 ± 23.00	441.37 ± 30.00	147.99 ± 20.00	195.27 ± 20.00	879.15 ± 25.00	1,813.82 ± 34.00
Flat	36.69 ± 3.00	222.89 ± 20.00	384.82 ± 23.00	529.49 ± 23.00	149.63 ± 26.00	211.53 ± 20.00	937.23 ± 24.00	1,548.45 ± 33.00
Zero tillage	35.57 ± 2.00	199.06 ± 20.00	379.63 ± 20.00	530.45 ± 25.00	150.40 ± 20.00	206.78 ± 20.00	961.57 ± 22.00	1,576.58 ± 30.00
LSD (0.05)	3.595[ns]	34.821[ns]	46.562[ns]	81.772[ns]	8.131[ns]	18.802[ns]	80.104[ns]	360.710[ns]
Interaction								
P × T	Ns	Ns	Ns	Ns	Ns	Ns	Ns	Ns
CV (%)	15.4	25.9	19.4	25.6	8.5	6.7	13.6	17.6

Note: LSD* significant at 5%; LSD ns: Not significant at 5%; Means followed by the same letter(s) are not statistically different at 5% level of probability

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Days to flowering, yield and yield related parameters

Generally, among intercrop combination investigated, the groundnut crops flowered earlier in 2021 cropping season when compared with 2020 season with approximately 6 days difference among corresponding intercrop combination (Table 4). Similar observation was noticed among the tillage practice, with approximately 5 days variations between 2020 and 2021 cropping seasons. The wide margins in Days to flowering observed between seasons among tillage practice and intercrop combination could be an indication that the variety of groundnut sown was not improved seed types. However, other reasons can be responsible for such variations, such as soil temperature, with warmer soils observed to speed up metabolic processes, so plant reaches flowering stage faster. Other reasons are rainfall and soil moisture variation (Mishra and Patel, 2017), sowing date effect (Reddy and Rao, 2018) and genotype (Zhang, et al., 2020).

Days to flowering, yield and yield related parameters did not respond significantly (p≥0.05) to tillage practice, nor were there significant (p≥0.05) interactions between tillage and intercrop combination on these parameters in 2020 and 2021 cropping seasons. However, haulm yield / ha, pod yield / ha, harvest Index (HI) and shelling percentage responded significantly to intercrop combination in both cropping seasons, while 100-seed weight responded to intercrop combination only in 2021 cropping season. Comparing yield related parameters among intercrop combination, better responses were obtained in 2020 cropping season when compared with 2021 season. Crops in 2020 cropping season did better in haulm yield / ha, pod yield / ha, harvest Index (HI) and mostly in shelling percentage and 100-seed weight (Table 4). Similar observations were noticed among the tillage practice where better yield and yield related outcomes were observed in 2020 cropping season compared with 2021 season.

Generally, sole cropped groundnut performed better than the intercrops regarding yield and yield related parameters. Better haulm yields were obtained in sole cropped plots (711.11 kg/ha and 637.04 kg/ha, respectively in 2020 and 2021 cropping seasons; better pod yields: 1,532 kg/ha and 1,367 kg/ha, respectively in 2020 and 2021 cropping seasons, better Harvest Index (53.26% and 36.78%, respectively in 2020, 2021 cropping seasons). The treatment recorded the best 100-seed weight in both seasons: 47.83, and 48.32g, respectively in 2020, 2021 cropping seasons. It also gave the best shelling percentage: 61.00% and 79.42%, respectively in 2020, 2021 cropping seasons. Data obtained on tillage practice did not show definite patterns as it affects these parameters. Better performance of sole cropped plots over the intercropped plots agrees with previous reports.

Table 4 Effect of crop combination, tillage practice and their interactions on days to flowering and yield related parameters

Treatment	Days to flowering		Haulm yield (kg/ha)		Pod yield (kg/ha)		Harvest index (%)		100-seed weight (g)		Shelling (%)	
	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021	2020	2021
Crop combination (P)												
Sole groundnut	32.67	26.83	711.11^{a}	637.04^{a}	1,532^{a}	1,367^{a}	53.26^{a}	36.74^{a}	47.83	48.32^{a}	61.00^{a}	79.42^{a}
2 maize:1 g/nut	34.17	28.17	355.56^{b}	289.89^{b}	1,283^{c}	1,226^{b}	28.32^{c}	22.64^{b}	44.83	39.76^{b}	53.17^{b}	60.65^{b}
2 g/nut:1 maize	33.25	27.67	362.96^{b}	266.67^{b}	1,332^{b}	1,234^{b}	33.23^{bc}	23.48^{b}	44.83	38.55^{b}	54.20^{b}	54.18^{b}
1 maize:1 g/nut	33.33	28.83	377.78^{b}	266.67^{b}	1,384^{b}	1,221^{b}	38.44^{b}	22.14^{b}	44.83	38.79^{b}	55.19^{b}	54.96^{b}
LSD (0.05)	1.60^{ns}	2.83^{ns}	77.12*	66.10*	70.60*	27.80*	7.06*	2.78	4.00^{ns}	4.98*	5.08*	6.50*
Tillage practice (T)												
Ridge	27.50	22.40	311.11	310.11	1,276	1,212	27.67	21.24	35.80	31.59	43.47	49.56
Flat	26.35	22.10	377.78	288.89	1,322	1,204	32.20	20.42	36.70	32.19	44.55	51.23
Zero tillage	26.20	22.40	378.78	288.89	1,320	1,213	32.08	21.34	36.90	35.48	46.12	48.74
LSD (0.05)	1.24^{ns}	0.64^{ns}	67.90^{ns}	78.79^{ns}	54.70^{ns}	21.50^{ns}	5.47^{ns}	2.15^{ns}	3.10^{ns}	3.86^{ns}	3.94^{ns}	5.04^{ns}
Interaction												
P × T	Ns	Ns	Ns	ns	Ns	Ns	ns	ns	ns	ns	ns	ns
CV (%)	7.3	4.5	28.9	31.1	27.9	16.1	27.9	16.1	13.3	18.3	13.8	15.8

Note: LSD* significant at 5%; LSD ns: Not significant at 5%; Means followed by the same letter(s) are not statistically different at 5% level of probability

Relative to LER (Table 5), among crop combination, the highest LERs were observed when one row of maize was intercropped with one row of groundnut (1.38 and 1.32, respectively in 2020 and 2021 cropping seasons) with the least LER observed when two rows of maize were intercropped with one row of groundnut (1.28 and 1.19, respectively in 2020 and 2021 cropping seasons). The rationale for better LERs in one row of maize intercropped with one row of groundnut compared with two rows of maize intercropped with one row of groundnut include fewer maize rows in the former enhances maize plant capture of more light, water and nutrients, improving their grains (Li et al., 2018). In addition, fewer maize populations in this treatment allows more photosynthetic active radiation to reach the lower groundnut canopy, boosting more pod formation among the treatment (Adu-Gyamfi, et al., 2015). In conclusion, groundnut N-fixation benefits maize more when the two species are in closer proximity, as root exudate and microbial activity are greater in the inter-row space (Singh and Reddy, 2017). Singh and Reddy (2017) found a 10 percent higher N transfer from groundnut to maize in 1:1 intercrops, translating into higher LER values. In addition, a more intimate mixture of two species can disrupt host – specific pest cycles, leading to lower damage and higher overall yields (Oyewole and Ogunlela, 2019). In summary, one row of maize with one row of groundnut layout reduces competition among maize plants, improves light and soil resource capture for groundnut, and enhances N-fixation and pest dilution effects; all of which contribute to higher LER than the more maize dense 2:1 pattern.

Among the tillage practice, zero tillage gave the highest LER (1.28 and 1.42, respectively in 2020 and 2021 cropping seasons) with planting on ridges giving the least LER (1.06 and 1.38, respectively in 2020 and 2021 cropping seasons). Generally intercropping was advantageous, showing various levels of intercropping efficiencies (Table 5). It has been previously reported that tillage and intercropping can significantly impact groundnut yield and yield components (Amanullah and Amanullah, 2017). This research outcome confirms this position. The better performance of zero tillage is also in agreement with previous reports (Amanullah and Amanullah, 2017) suggesting that zero tillage practices tend to have higher soil water contents, which benefits groundnut growth, especially when intercropped with maize; as intercropping groundnut with maize under zero tillage conditions can lead to improved soil water conservation, resulting in better yields.

Table 5 Effect of crop combination, tillage practice on LER in Anyigba in 2020 and 2021 cropping seasons

Treatment	Land equivalent ratio (LER)		Intercropping Efficiency over sole cropping (%)	
	2020 cropping	2021 cropping	2020 cropping	2021 cropping
Crop combination				
Sole groundnut	-	-	-	-
2 maize:1 g/nut	1.28	1.19	28	19
2 g/nut:1 maize	1.29	1.28	29	28
1 maize:1 g/nut	1.38	1.32	38	32
Tillage practice				
Ridge	1.06	1.38	06	38
Flat	1.25	1.40	25	40
Zero tillage	1.28	1.42	28	42

Conclusions

With the highest Intercropping Efficiency over sole cropping (38 % and 32%, respectively in 2020 and 2021 cropping seasons) recorded when one row of groundnut was intercropped with one row of maize, this level of crop combination will offer farmers the best returns on cultivated land.

The fact that intercropping on Zero tillage performed better (28% and 42%, respectively in 2020 and 2021 cropping seasons) than sowing on the Flat, which recorded Intercropping Efficiency over sole cropping of 25% in 2020 and 40% in 2021, with cropping done on the Ridge giving the least performance, is an indication that farmers may not need conventional tillage practice before seed sowing in the experimental area, which will be cost saving for these farmers.

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