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Effect of Intercropping on Nitrogen Fixation of Three Groundnut (*Arachis hypogaea* L) Genotypes in the Guinea Savanna Zone of Ghana

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

An experiment was conducted on the research farm of the Savanna Agricultural Research Institute (SARI), Nyankpala, in the Guinea savanna agro-ecology to study the nitrogen fixation performance of three groundnut genotypes (Jenkaar, Kpanieli and Nkosuor) intercropped with maize (*Obatanpa* variety). The experiment was laid out in randomized complete block design with four replications. Treatments evaluated were sole groundnut, sole maize, single-row groundnut intercropped with single-row maize (G1M1), double row groundnut intercropped with single-row maize (G2M1), single-row groundnut intercropped with double-row maize (G1M2) and double-row groundnut intercropped with double-row maize (G2M2). Data collected included canopy width, number of branches plant^{-1}, above ground dry matter, residue and seed N, stover yield and stover N (kg N ha^{-1}). The results showed that with the exception of Kpanieli, intercropping significantly ($P<0.05$) reduced the growth parameters and nitrogen fixation of the groundnut genotypes. Row patterns that allowed more space and light penetration significantly ($P<0.05$) improved nitrogen fixation. Even though all three groundnut genotypes performed within the reported levels with

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regard to nitrogen fixation, the Kpanieli genotype intercropped with maize using the double row groundnut-single row maize (G2M1) pattern was more beneficial.

Keywords: Agro-ecology; intercropping; genotype; sustainable; smallholder; farm family.

1. INTRODUCTION

Intercropping is closely associated with peasant agricultural practices in the developing world and involves the simultaneous growing of two or more crops on the same field during the season [1,2,3]. Established advantages of the practice include insurance against total crop failure, increase in total productivity per unit area through maximum utilization of land, labour and growth resources [4,5,6], good soil cover for the control of erosion [7], suppression of weeds [8] and reduction in insect pest infestation [9].

In the Guinea savanna zone, low soil N fertility has been identified as the major constraint to crop production [10]. Unfortunately, current prices of chemical fertilizers are unaffordable to the smallholder farm families who, in most cases have very limited financial resources or none at all. The inclusion of legumes as part of the mixed farming systems by such smallholders help to mitigate the effect of the declining soil fertility on crop yield [11,12,13,14].

In Ghana's Guinea savanna zone, groundnut and maize form the number one grain legume and cereal staples respectively, grown by farm families. The two crops are often grown as sole crops or as partners in an intercrop. In response to this practice, several studies have been conducted in Ghana and elsewhere to evaluate the productivity and profitability of such system [15,16]. Other studies in Ghana have largely concentrated on the diseases, pests and pod yield [15,16,17]. No efforts have been made to evaluate new groundnut genotypes for compatibility in such mixed cropping systems with regard to their ability to nodulate and fix nitrogen, an essential requirement for sustainability of smallholder production systems in the face of declining soil fertility and competing uses for limited land. This is in spite of the fact that intercropping has a modifying effect on temperature, soil moisture, light interception and photosynthesis, available nutrient use and activity of the native rhizobia, all of which affect nodulation and nitrogen fixation by the legume [18,19,20].

Groundnut has been reported to fix about 21-206 kg N ha^{-1} per year [20]. In small holder intercropping systems, the ability of the legume to grow without N fertilization permits better allocation of limited resources, thus lowering the risk of total crop failure, although application of N fertilizer to maize in the intercrop has been reported to result in significant reduction in nodulation and nitrogen fixation by the groundnut [19]. This reduction however does not directly result from the addition of fertilizer N to the soil but from the shade of the vigorously growing cereal that reduces groundnut photosynthesis [19]. Earlier study involving the evaluation of these genotypes under sole cropping [21] reported average pod yields of 1.64 t ha^{-1} (Jenkaar), 0.76 t ha^{-1} (Kpanieli) and 0.94 t ha^{-1} (Nkosuor) compared to national average pod yield of 0.85 t ha^{-1} in Ghana [22]. Pod yields obtained from these varieties when intercropped with maize [17] were however reversed for each genotype; 0.83 t ha^{-1} (Jenkaar), 1.16 t ha^{-1} (Kpanieli) and 0.73 t ha^{-1} (Nkosuor), indicating that a promising genotype under sole crop should not be lightly recommended for intercropping without prior test of its compatibility with the candidate intercrop partners. Previous work regarding nitrogen fixation of intercropped groundnut showed that association of groundnut with a cereal resulted in reduced nodulation and nitrogen fixation in all cases [19]. Recent study [23] have reported nodule number of 206.1, 174.9 and 216.6 per plant respectively for Jenkaar, Kpanieli and Nkosuor genotypes under sole groundnut system in the Guinea savanna, fixing stover N of 40.6, 39.4 and 37.0 kg N ha^{-1} respectively. Because the residual effect of legume nitrogen fixation depends on the proportion of the N retained in non-harvested residue, the amount of residue and its rate of mineralization [19], the planting of groundnut in maize could limit the amount of nitrogen fixed by the legume thus potentially making less N available for subsequent cropping. In an attempt to mitigate the consequence of such intercropping practices on groundnut nitrogen fixation the study was conceived to evaluate these genotypes for compatibility in ground-maize intercropping systems. The objective was to select the most compatible genotype and determine suitable row arrangement for intercropping groundnut with maize in the Guinea savanna zones without significant reductions in pod production and nitrogen fixation.

2. MATERIALS AND METHODS

2.1 Experimental Design and Treatments

The experiment was laid out in randomized complete block design with four replications and six treatments. The groundnut genotypes were first rate certified seed obtained from Crop Research Institute (Jenkaar and Nkosuor) and Savanna Agricultural Research Institute (Kpanieli) with a determinate growth habit and 110 days maturity period. The maize (*Obatanpa* variety), also obtained from Savanna Agricultural Research Institute had an average maturity period of 105-110 days. The treatments evaluated were:

1. Sole maize planted at 60 cm x 40 cm giving plant population density of 41, 667 plants per hectare.
2. Sole groundnut planted at 30 cm x 15 cm [21] giving plant population density of 222,222 plants per hectare.

G1M1: 1 row of groundnut (90 cm x 15 cm) alternated with 1 row of maize (90 cm x 40 cm) giving plant composition 33.3 % groundnut and 66.7 % maize.

G2M2: 2 rows of groundnut (67.5 cm x 15 cm) alternated with 1 row of maize (135 cm x 40 cm) giving plant composition of 55.6 % groundnut and 44.4 % maize.

G1M2: 1 row of groundnut (165 cm x 15 cm) alternated with 2 rows of maize (82.5 cm x 40 cm) giving plant composition of 26.8 % groundnut and 73.2 % maize.

G2M2: 2 rows of groundnut (105 cm x 10 cm) alternating with 2 rows of maize with maize (105 cm x 40 cm) giving plant composition of 42.8 % groundnut and 57.2 % maize.

2.2 Site Characteristics and Management Operations

Nyankpala (9°25'N, 1°00' W, 183 metres above sea level) is a farming community located 16 km west of Tamale with gentle slope of about 2 % and evidence of soil (Tingoli series) strongly disturbed by sheet erosion [21]. The land, which was previously cropped to maize was left to fallow for two years prior to the establishment of the trial. The climate of Nyankpala is warm, semi-arid with mono-modal annual rainfall of up to 1,200 mm which falls mostly between May and September. The average monthly atmospheric temperatures range from 26°C to a 39°C with an annual mean of 32°C [21]. A single ploughing operation, followed by a single harrowing was carried out by a tractor prior to lining and pegging. Two seeds and one seed per hole respectively of maize and groundnut were planted on flats and the first weeding done with a hand hoe 4 weeks after sowing (WAS). 60 kg N / ha of NPK (23:10:5) was applied to the maize plants 2 WAS. The fertilizer was placed in holes drilled close to the maize plants and covered with soil. A top-dressing of 50 kg Sulphate of Ammonia per hectare was applied to the maize at 6 WAS after the second weed management operation using the same localized placement method.

2.3 Data Collected

2.3.1 Growth parameters

Canopy spread of treatments were measured at 8 WAS. A quadrant was placed on the row to get a square. The measurement was then made from the last leaf on one side of the row to the last leaf on the other side with a measuring tape. Five such measurements were taken per plot and the average determined. The number of branches of five randomly selected and tagged plants from each net plot was determined by counting at maturity. The five plants were then harvested at maturity, oven dried at 80°C for 72 hours and the dry weight per plant at harvest determined. Groundnut haulms from each net plot were dried and weighed after harvest. The weights obtained were then converted to stover yield (t ha^{-1}) for each treatment in both years.

2.3.2 Nodulation and nitrogen fixation

Five plants from the two border rows were randomly selected and gently dug out at 6 WAS [23]. The plants were then washed through a fine sieve in water to remove soil particles. The number of nodules on each plant was then determined and the average nodules per plant calculated. The technique used to estimate the amount of N_2-fixed by treatments was the Total Nitrogen Difference method [24]. The amount of nitrogen in the groundnut genotypes were compared to that of a sole maize crop grown to maturity on the same land. The difference between the two crops on per plant basis with respect to residue and seed nitrogen was regarded as the quantity of N (%) provided by the groundnut biological nitrogen fixing system. The procedure followed to estimate the residue and seed N of the groundnut varieties and the maize are as follows [23]:

$$\text{N fixed} = \text{N yield}_{fix} - \text{N yield}_{ref}$$
$$\%\ \text{Ndfa} = 100(\text{N yield}_{fix} - \text{N yield}_{ref}) / \text{N yield}_{fix}$$

Where:

% Ndfa percentage of plant nitrogen derived from atmosphere
N $yield_{fix}$ nitrogen yield by N_2-fixing system (groundnut)
N $yield_{ref}$ nitrogen yield by reference crop (maize)

Stover N (kg N ha^{-1}) was then determined as the product of the stover yield (t ha^{-1}) of treatments and the nitrogen concentrations (% N) obtained from their respective residue analysis, based on the assumption that the groundnut and the maize plants assimilate identical amounts of soil and fertilizer nitrogen [20].

2.4 Statistical Analysis

Data on plant growth and nitrogen fixation were analysed using ANOVA and the treatment means separated by least significant difference.

3. RESULTS

3.1 Effects of Intercropping

Apart from the intercropped Kpanieli, the number of branches $plant^{-1}$ of groundnut genotypes in both years were significantly ($P<0.05$) reduced by intercropping (Table 1.1). Dry matter production of the intercropped Nkosuor in both years was significantly ($P<0.05$) lower than those of intercropped Jenkaar and Kpanieli, which recorded dry matter values similar to the sole groundnut crop (Table 1.1). Because of its relatively lower dry matter $plant^{-1}$, the stover yield of the intercropped Nkosuor was only similar to that of intercropped Jenkaar, which were both significantly ($P<0.05$) lower than those of the sole groundnut and intercropped Kpanieli (Table 1.1). The number of nodules $plant^{-1}$ of the three genotypes were significantly ($P<0.05$) reduced by intercropping with maize (Table 1.2). Therefore, the residue, seed and total N (%), as well as stover N (kg N ha^{-1}) of the all three groundnut varieties were reduced in both years. The stover N of the intercropped Kpanieli and Nkosuor were however similar and significantly ($P<0.05$) larger than that of the intercropped Jenkaar in both years (Table 1.2).

3.2 Effects of Row Arrangement

Generally, groundnut growth parameters were improved by the double groundnut row intercropping arrangement. The number of branches $plant^{-1}$ in both years were significantly ($P<0.05$) higher under G2M1 and G2M2 row arrangements (Table 1.1). Row arrangements that increased the population density of groundnut in the groundnut-maize intercrop led to slight reductions in their canopy diameters in 2007 (Fig 1.1a) and 2008 (Fig 1.1b) which translated into reductions in dry matter production $plant^{-1}$ since canopy diameter was found to correlate positively with dry matter production in 2007 (Fig 1.2a) and 2008 (Fig 1.2b). Consequently, the stover yield of the G1M2 row arrangement was significantly ($P<0.05$) lower than those of the other row arrangements in both years. The stover yield of the G2M2 row arrangement was also significantly ($P<0.05$) lower than those of the remaining row arrangements (Table 1.1). Row arrangement did not significantly ($P>0.05$) alter the number of nodules $plant^{-1}$ in both years (Table 1.1). Generally, the residue, seed and total N (%) in both years were highest under the G2M1 row arrangement (Table 1.2). The influence of row arrangement on residue N (%) was significant only in 2007 when the N in the residue of groundnut grown under the G1M1 arrangement was found to be significantly ($P<0.05$) lower (Table1.2). The seed N of the G2M1 row arrangement in both years was significantly ($P<0.05$) higher than those of groundnut grown under G1M2 and G2M2 row arrangements (Table 1.2). As with residue and seed N (%), stover N of groundnut grown under G2M1 row arrangement was the highest in both years, and was significantly different ($P<0.05$) from those of the G1M2 and G2M2 arrangements in 2007, and all other row arrangements in 2008 (Table 1.2).

4. DISCUSSION

The characteristic reductions in growth parameters recorded by all three intercropped groundnut genotypes confirm the behaviour of under-storey crops [19]. These reductions in dry matter production reflected in nodulation and accumulation of N in both groundnut seed and residue [19,20]. The reduced residue N, coupled with the relatively lower stover yield led to a reduced stover N in the intercropped groundnut compared to the sole crop. This was so because nodulation and nitrogen fixation depends heavily on dry matter production by the crop [20] which was significantly reduced by intercropping with maize. Dry matter production per hectare was also reduced by intercropping, further reducing stover N (kg N ha^{-1}). The nodule numbers recorded by the genotypes were lower than that reported for the same genotypes grown as sole crops [23]. The relatively higher stover N recorded under the current study points to the fact that the few nodules recorded were probably more effective than the numerous nodules reported by earlier research [23].

The performance of the double row groundnut intercropped with single or double row maize with regard to number of branches, dry matter plant^{-1} and stover yield were probably due to less shading which enabled the groundnut crop to make use of the starter nitrogen applied to the maize for increased photosynthesis and growth. A reverse observation was made in the single row groundnut intercropped with double row maize which performed poorly with regard to these growth parameters. This poor performance could be attributed to the heavy shading experienced by a single row of groundnut embedded between two rows of maize [19].

Table 1.1. Effects of intercropping and row arrangement on the number of branches and dry matter production per plant, stover yield per hectare and number of nodules per plant in 2007 and 2008

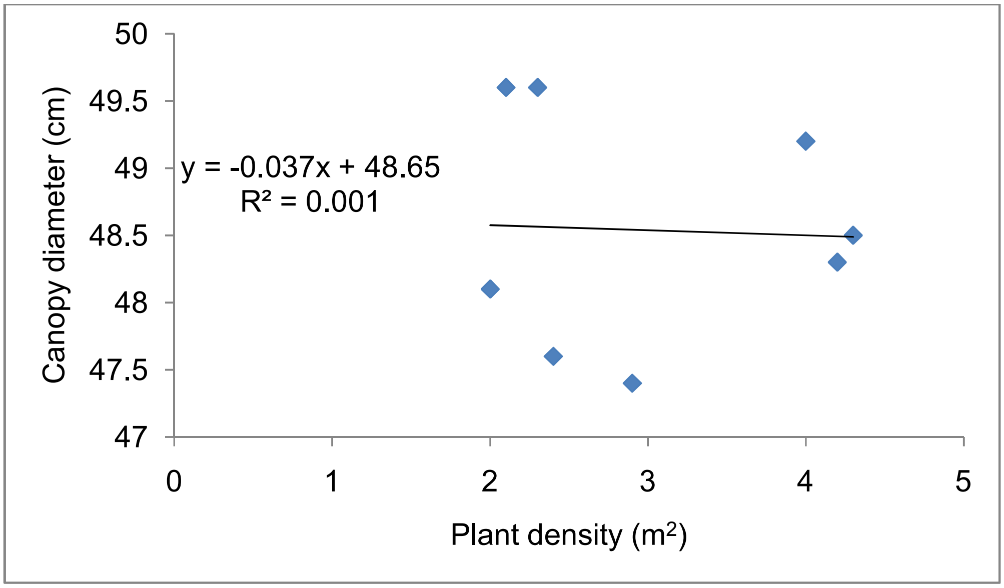
Treatments	Branches plant^{-1}		Dry matter (g plant^{-1})		Stover yield (t ha^{-1})		Nodules plant^{-1}	
	2007	2008	2007	2008	2007	2008	2007	2008
Crp sys								
Sole groundnut	8.8^a	8.6^a	118.5^a	127.5^a	3.066^a	3.505^a	90.3^a	82.7^a
Jenkaar-maize	6.1^b	6.8^b	106.7^b	123.3^a	1.524^{bc}	1.509^c	62.1^b	61.3^b
Kpanieli-maize	8.4^a	7.7^{ab}	106.7^b	121.0^a	1.977^b	1.987^b	66.7^b	67.0^b
Nkosuor-maize	6.8^b	6.9^b	93.3^c	104.0^b	1.318^c	1.518^c	67.2^b	60.8^b
Lsd $_{0.05}$	1.3	1.2	10.1	7.8	0.47	0.27	17.2	11.4
Row arrangement								
G1M1	5.9^b	6.5^b	107.4^a	120.9^a	1.581^a	1.548^a	60.5	60.6
G2M1	7.7^a	7.5^a	100.0^a	120.7^a	1.516^a	1.514^a	68.7	67.8
G1M2	5.4^b	6.8^b	81.5^b	96.0^b	0.762^c	0.722^c	58.9	59.1
G2M2	7.8^a	7.7^a	103.7^a	115.5^a	1.108^b	1.069^b	68.1	65.8
Lsd $_{0.05}$	0.7	0.6	9.8	15.6	0.13	0.37	ns	ns
CV (%)	18.2	20.1	11.7	23.2	17.5	25.0	27.2	17.9

Note: Means followed by the same superscripted letter are not significantly different. N (nitrogen), g plant^{-1} (grams per plant), t ha^{-1} (tons per hectare), G1M1 (1 row groundnut, 1 row maize), G2M1 (2 rows groundnut, 1 row maize), G1M2 (1 row groundnut, 2 rows maize) and G2M2 (2 rows groundnut, 2 rows maize)

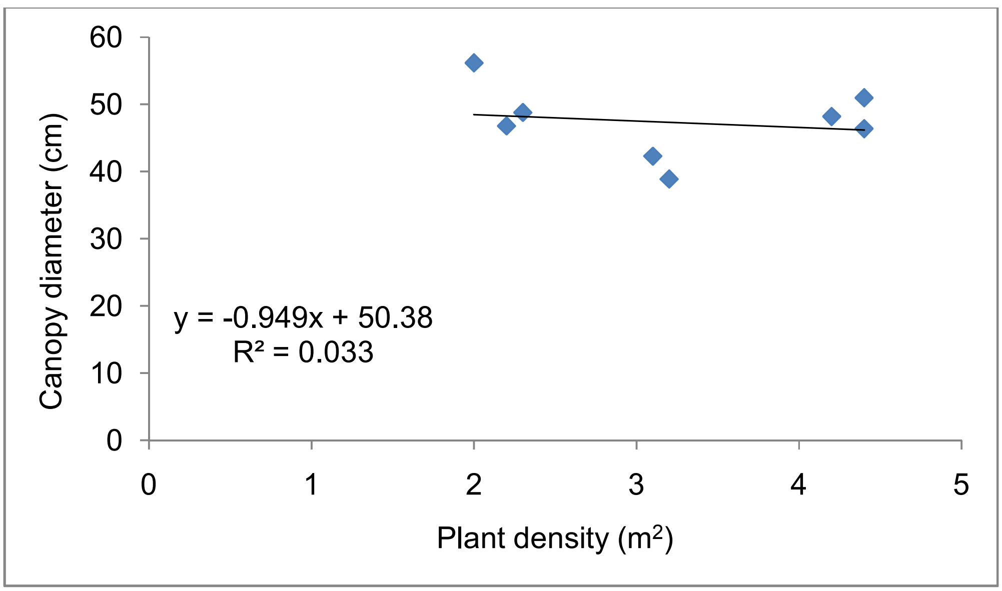
Table 1.2. Effects of intercropping and row arrangement on stover N and percent residue, seed and total nitrogen of groundnut varieties in 2007 and 2008

Treatments	Residue N (%)		Seed N (%)		Total N (%)		Stover N (kg ha^{-1})	
	2007	2008	2007	2008	2007	2008	2007	2008
Crp sys								
Sole groundnut	2.98^a	2.45^a	2.76^a	3.50^a	5.74^a	5.95^a	50.0^a	56.5^a
Jenkaar-Maize	1.88^c	1.46^b	2.04^b	1.91^b	3.92^c	3.37^c	31.2^c	23.5^c
Kpanieli-Maize	2.07^c	1.52^b	1.96^b	1.94^b	4.03^c	3.48^{bc}	45.2^{ab}	35.7^b
Nkosuor-maize	2.52^b	1.81^b	2.21^b	2.53^b	4.73^b	4.34^b	37.6^b	33.5^b
Lsd $_{0.05}$	0.43	0.51	0.50	0.72	0.46	0.73	11.5	3.1
Row arrangement								
G1M1	1.18^b	1.60	2.02^b	1.94^b	3.20^b	3.54^{ab}	33.4^a	21.2^b
G2M1	2.41^a	1.76	2.54^a	2.61^a	4.95^a	4.37^a	36.9^a	26.6^a
G1M2	1.71^a	1.73	1.55^c	1.15^c	3.44^b	2.88^b	13.0^b	7.2^d
G2M2	2.32^a	1.23	1.67^c	1.53^{bc}	2.99^b	2.76^b	16.8^b	13.0^c
Lsd $_{0.05}$	0.91	ns	0.37	0.55	1.33	1.72	9.4	4.0
CV (%)	20.0	23.6	19.6	26.0	24.3	21.5	25.0	13.3

Note: Means followed by the same superscripted letter are not significantly different. N (nitrogen), kg ha^{-1} (kilograms per hectare), G1M1 (1 row groundnut, 1 row maize), G2M1 (2 rows groundnut, 1 row maize), G1M2 (1 row groundnut, 2 rows maize) and G2M2 (2 rows groundnut, 2 rows maize)



(a)

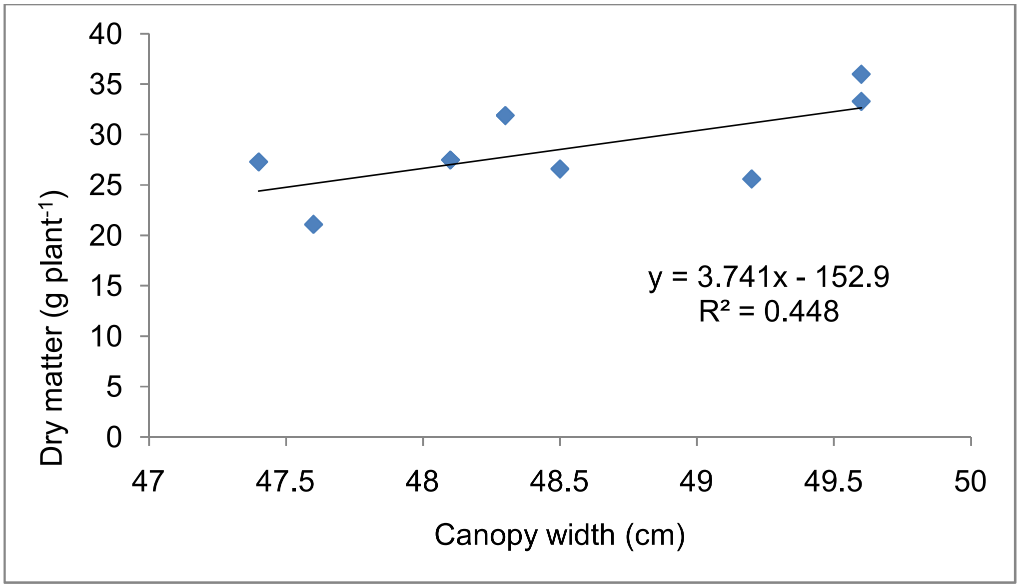


(b)

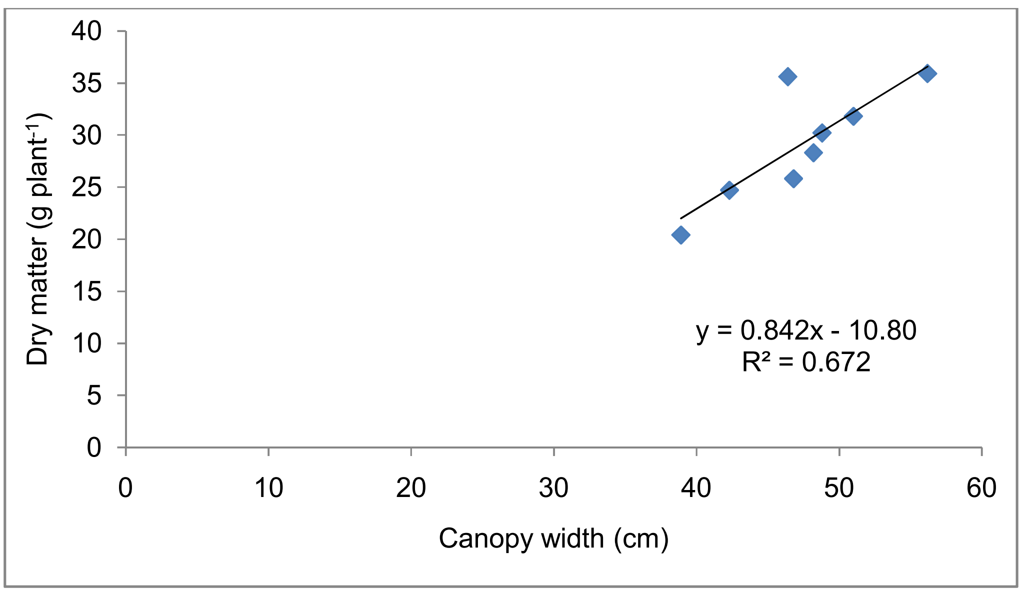
Fig. 1.1. Relationship between plant population density and canopy diameter in 2007 (a) and 2008 (b)

In both years, there was a slight negative relationship between groundnut population density and its canopy spread. Increasing groundnut population density therefore led to slight reductions in canopy size

Nodulation however, was unaffected by row arrangement in the groundnut-maize intercrop. This was probably as a result of the availability of sufficient phosynthates for the process of nodule formation. Nodule activity however was affected by row pattern as shading by the maize increased, resulting in better residue N in 2007 and seed N in both years by double row groundnut intercropped with single row maize which potentially received more solar radiation for photosynthesis. The significantly larger Stover N of the G2M1 and G1M1 were therefore primarily driven by high residue N and stover yield for the G2M1 row pattern, and mainly large stover yield in the G1M1 row pattern due to high plant population density.



(a)



(b)

Fig. 1.2. Relationship between canopy size of groundnut plants and dry matter production per plant in 2007 (a) and 2008 (b)

There was a weak positive correlation between canopy width and dry matter production in 2007 (a) and a strong positive correlation between the two in 2008 (b). Generally, lower plant densities led to bigger plants with wider canopies which then translated into higher dry matter production per plant in both years

The stover N values recorded by this study compare favourable with the 37-40.6 kg N ha^{-1} [23] and fall within the 21-206 kg N ha^{-1} range [20] reported in sole groundnut systems. The values were however, well below the 60 kg N ha^{-1} [25,26] and 54-58 kg N ha^{-1} [27,28]. Groundnut-maize intercropping system can therefore help address the challenges identified [10] while providing cereal for household use and groundnut for cash income on sustainable low external input basis.

5. CONCLUSION

For the purpose of benefiting from higher pod yield and N_2-fixation in groundnut-maize intercropping systems in the savanna zones, the Kpanieli genotype could be planted using the double row groundnut intercropped with a single row of maize (G2M1).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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