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The Effect of Combining Calcium, Nitrogen and Phosphorus Fertilizer Application on Groundnut Yield in Smallholder Farmers' Sole Cropping System

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Abstract

A field experiment was conducted to determine the effect of combining Ca, N and P on yield of groundnuts. The 3^3 factorial experiment involved applying the nutrient-elements at three levels of P at P_0, P_{30} and P_{60} kg P ha^{-1}; Ca at Ca_0, Ca_{100} and Ca_{200} kg Ca ha^{-1} and three levels of starter N at N_0, N_{10} and N_{20} kg N ha^{-1}. Treatment combinations were randomly allocated in each of the three blocks. Groundnut variety MGV 5 was grown as a sole-crop for two consecutive growing seasons of 2014/15 and 2015/16. Results revealed that application of Ca, N and P either alone or in combination resulted in significant increase in the 100 seed weight and yields of haulm, pods and kernels of groundnuts. The application of the fertilizer combination at the rate of $Ca_{200}N_{20}P_{60}$ kg ha^{-1} had an additive synergistic effect on MGV 5 and consequently resulted in the highest kernel yield of 4.18 t ha^{-1}, pod yield of 6.72 t ha^{-1}, haulm yield of 5.87 t ha^{-1} and the highest 100 seed weight of 102.7 g. It was, therefore, concluded that the fertilizer combination of $Ca_{200}N_{20}P_{60}$ kg ha^{-1} is appropriate for obtaining optimum yields of groundnuts.

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Introduction

Groundnuts are produced virtually throughout Zambia (MAFF, 2000; Mukuka and Chisanga, 2014) under rain fed conditions (Sichoongwe et al., 2014). The crop is ranked second to maize both in terms of production and area cultivated in Zambia (Ross and Klerk, 2012; Mukuka and Shipekesa, 2013). However, there has been a decline in production with the national average yields as low as 0.642 t kernels ha^{-1} being common (FAOSTAT, 2014).

Central Province, Chisamba District inclusive, commonly produce yields of groundnut kernels as low as 0.34 t ha^{-1} (CSO and MACO, 2011). The livelihoods of more than 80 % of smallholder farmers in Chisamba entirely depend on groundnut and maize production (CSO and MACO, 2011). Therefore, low yields like 0.34 t ha^{-1} (CSO and MACO, 2011) deprive smallholder farmers of their much needed protein and income (Sitko et al., 2011).

Low kernel yields have been attributed to the decline in soil fertility caused by continuous mono-cropping, unbalanced fertilization, practise of low external input agriculture (LEIA) and early burning which leaves the soil bare and susceptible to erosion (Kabamba and Kankolongo, 2009; MAL, 2013). Practising LEIA without replenishment of the mined nutrients (Umar et al., 2013) has aggravated the decline in soil fertility (Umar, 2012; Thierfelder et al., 2013) resulting in low kernel yields. This is exacerbated by soils which are inherently low in N and P (GART, 2011), are acid in nature especially in high rainfall areas of Zambia (GART, 2011; MAL, 2013) and contain low soil organic matter (SOM) (Kabamba and Kankolongo, 2009; Thierfelder et al., 2012). Acid soils tend to have high levels of Al^{3+} and Mn^{2+} which are toxic to plants (Millaleo et al., 2010; GART, 2011; MAL 2012; Nweke, 2013; Kebeney et al., 2015) and impede crop production in Zambia (GART, 2011; MAL, 2012). The acid soils are also low in Ca which results in aborted pods in groundnuts, a condition commonly referred to as "pops" (MAFF, 1989; Siamasonta, 1995). Low soil fertility is the more reason why national average yields as little as 0.64 t groundnuts ha^{-1} are persistent (FAOSTAT, 2014). Therefore, increase in the production of groundnuts is desirable. This can be achieved through application of optimum and appropriate rates of fertilizers (Veeramani and Subrahmaniyan, 2011; Arnold, 2014) such as Ca, N and P (Baughman and Dotray, 2015).

The major impediments to groundnut production are Ca and P deficiencies (Mupangwa and Tagwira, 2005). Application of P to groundnuts is important for not only root growth but also for the whole physiological development of the crop (FAO, 1984; FAO, 2006). Starter N doses enhance the crop's development before it starts fixing N (FAO, 2006). Calcium is another critical nutrient in groundnut production (FAO, 1984; Baughman and Dotray, 2015). It is important for pod development, seed filling and crop performance (FAO, 1984; MAFF, 1989; Baughman and Dotray, 2015). It is, therefore, essential that the appropriate nutrient needs of groundnuts especially those of new cultivars, are met (Arnold, 2014). However, there is paucity of information on the fertilization of groundnuts in Zambia. The dearth of information is compounded by the fact that most of the previous studies on groundnuts in Zambia focused on breeding programs, plant population, diseases, pests and spacing, with a few complementary studies on nutrition. A few previous studies focused on Ca fertilization but not on N and P fertilization (MAFF, 1989). Apart from outdated basal recommendation of NPK (MAFF, 1989), there are no previous studies that combined Ca, N and P fertilization for the improvement of groundnut productivity. It is from this background that this study was commissioned to specifically determine the effect of Ca, N and P fertilizer application on yield of groundnuts under smallholder sole cropping systems in Zambia.

Materials and methods

Field study

Two field trials were conducted at Golden Valley Agricultural Research Trust (GART) for two consecutive growing seasons of 2014/15 and 2015/16. The study site is located in Chisamba District, in the Central Province of Zambia. The District is located between latitude 14° 30' and 15° 00' S and longitudes 28° 00' and 28° 30' E. It is 1 138 m above sea level. Chisamba District is located in agro-ecological zone (AEZ) II (a) which receives comparatively high and well distributed rainfall ranging from 800 – 1 000 mm and is one of the two most productive AEZs in the country (Bunyolo et al., 1995; MAFF, 2002). The mean annual temperature in AEZ II (a) range from 14.31 to 27.31°C during the 120 – 150 days of the region's growing season (MAFF, 2002; GART, 2011). The region is characterised by leached clayey to loamy soils, coarse sandy loams and sandy soils of the Kalahari sand (Bunyolo et al., 1995). The District is dominated by smallholder farmers whose livelihoods depend on rain fed groundnut and maize production (CSO and MACO, 2011). The region contributes over 60% of the total national groundnut production (CSO and MACO, 2011).

The rainfall distribution for both seasons, 2014/15 and 2015/16, was presented in Table 1. In this study, periods of 6 or more days of consecutively no rainfall were recorded as intra-seasonal dry spells. The dry spells were recorded more in February and March of season one. March was the driest month in the 2014/15 growing season with 25 days of no rainfall (Table 1). The intra-seasonal dry spell in March of 2015/16 was only for 14 days. Although the cumulative total rainfall of both growing seasons only differed by 10 mm, the distribution in season two was more uniform.

Chemical and physical properties of the soil at the study site were presented in Table 2. The soil belongs to *Kazwanya* family, an Alfisol (MAFF, 1992; SSU, 2003) with a sandy clay loam top soil texture class. The soil is of low soil fertility due to low CEC, total N, available P, S and deficient in B. To mitigate the deficiency, 1 kg B ha^{-1} supplied by H_3BO_3 was applied at planting by broadcasting. The pH of the soil was 5.14 and according to ratings by Landon (1991), it is moderately acidic.

Table 1. The rainfall distribution of Chisamba District in the growing season of 2014/15 and 2015/16.

Month 2014/15	Total rainfall mm	Total cumulative rainfall	Number of rainy days	Total days of dry spells ≥ 6 days of no rainfall
November	53.3	53.3	2	12
December	211.3	264.6	11	5
January	233.5	498.1	13	5
February	124.7	622.8	12	14
March	56.6	679.4	4	25
April	57.5	736.9	5	Rainfall stopped on 14 April
2015/16				
November	102.2	102.2	3	12
December	189	291.2	11	8
January	114.5	405.7	8	6
February	112.6	518.3	9	14
March	173.4	691.7	7	14
April	34.9	726.6	3	Rainfall stopped on 9 April

Table 2. Soil chemical and physical characteristics of the study site.

Parameter	Units	GART
pH (0.01M $CaCl_2$)		5.14
Organic matter	%	4.48
Total nitrogen	%	0.14
Available P	mg kg^{-1}	0.04
Available S	mg kg^{-1}	0.40
K	cmol kg^{-1}	0.21
Ca	cmol kg^{-1}	2.25
Mg	cmol kg^{-1}	1.06
Na	cmol kg^{-1}	0.02
Al^{3+}	cmol kg^{-1}	0.64
H^+	cmol kg^{-1}	0.48
Exchangeable acidity	cmol kg^{-1}	1.12
CEC	cmol kg^{-1}	8.00
Total exchangeable bases	cmol kg^{-1}	3.54
Base saturation	%	44.22
Exchangeable sodium percentage	%	0.24
Cu	mg kg^{-1}	2.68
Fe	mg kg^{-1}	19.04
Mn	mg kg^{-1}	21.00
Zn	mg kg^{-1}	0.76
B	mg kg^{-1}	< 0.001
Sand	%	56.40
Clay	%	25.60
Silt	%	18.00
USDA texture class	%	Sandy clay loam

The 3^3 factorial experiments to determine the appropriate rate combination of Ca, N and P fertilizers for optimum groundnut production were conducted. The three nutrients were applied at three levels of P at P_0 (control), P_{30} and P_{60} kg P ha^{-1}; Ca at Ca_0 (control), Ca_{100} and Ca_{200} kg Ca ha^{-1} and three levels of starter N at N_0 (control), N_{10} and N_{20} kg N ha^{-1}. In this study, the three levels of the fertilizers were referred to as low (0), intermediate (e.g. 100 kg Ca ha^{-1}) and high level (e.g. 200 kg Ca ha^{-1}) of either Ca or N or P application. The fields were divided into 3 blocks containing 27 experimental units measuring 4.5 m × 1.00 m. Treatment combinations were randomly allocated in each block. Groundnut (MGV 5) was grown as a sole-crop for two consecutive growing seasons from 2014/15 to 2015/16. At planting, urea (H_2NCONH_2) and SSP [Ca $(H_2PO_4)_2$] were side-dressed in the same furrow, 5 cm from station. Gypsum ($CaSO_4$), to supply Ca, was applied at 50 % flowering stage by cautiously dusting it on the side of the plant, to minimise shedding of flowers. High level crop management was implemented to minimise biotic stresses. Rainfall data were collected from the weather station at GART Chisamba. The data collected were 100 seed weight and yields of haulm, pods and kernels of the groundnut crop.

Statistical analysis

The data were evaluated by analysis of variance using the GenStat programme (GenStat, 2012). The means were separated at α = 0.05, by the Duncan's Multiple Range Test (DMRT) (Montgomery, 2000).

Results and discussion

The main effect of Ca, N and P fertilizer application on the kernel yield of groundnuts

The kernel yields of groundnuts increased linearly with increasing levels of Ca applied (Fig. 1). The kernel yields attributed to Ca main effect ranged from 2.25 to 2.92 t ha^{-1}. There was a highly significant difference amongst the means of kernel yields due to Ca main effect (p = 0.003). However, the means of kernel yields attributed to 100 kg Ca ha^{-1} and 200 kg Ca ha^{-1} were non-significantly different. Groundnuts responded to 100 kg Ca ha^{-1} and also to 200 kg Ca ha^{-1} to give a 22.48 % and 29.89 % increase in kernel yields, respectively. The results were in agreement with Kirthisinghe et al. (2014) who reported that application of 100 kg Ca ha^{-1} to groundnuts in Sri Lanka increased the kernel yields by 42.11 %.

Groundnuts also responded to P main effects with a linear increase in kernel yields as P levels were increased (Fig. 1). The groundnut crop responded to P main effect at intermediate and high level of application which resulted in increase of kernel yields by 33.18% (with 60 kg P ha^{-1}) and 22.2% (with 30 kg P ha^{-1}). The findings of the current study are consistent with previous results reported by Mupangwa and Tagwira (2005) in Zimbabwe who indicated that application of 34 kg P ha^{-1} increased kernel yields by 51%. The observation of the current study is also falling in line with Kalita et al. (2015) who applied 21.82 kg P ha^{-1} to groundnuts in India and reported that it significantly increased pod and kernel yields.

There was a highly significant difference amongst the means attributed to N main effects (p = 0.036). It was also observed that there was a linear increase in grain yield of groundnuts with increasing levels of starter N applied (Fig. 1). The kernel yields in the field supplied with N alone ranged from 2.33 (0 kg N ha^{-1}) to 2.88 t ha^{-1} (20 kg N ha^{-1}). The results are in line with Kalita et al. (2015) who applied starter N of 60 kg N ha^{-1} to groundnuts in Iran to result in kernel yields of 1.38 t ha^{-1}.

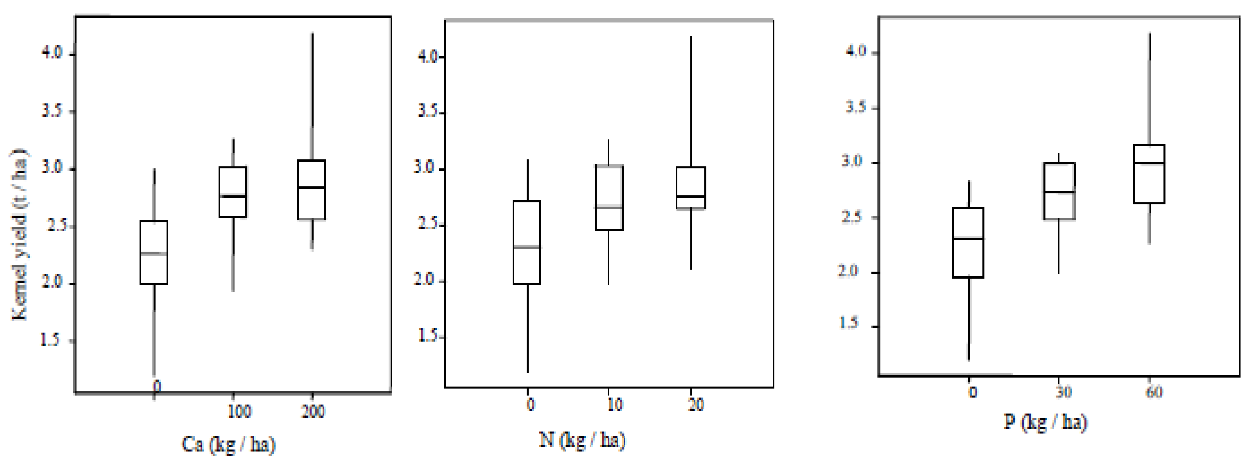

Fig. 1: The main effect of Ca, N and P fertilizer application on the kernel yield of groundnuts grown at GART in Chisamba District.

The interactive effect of combined Ca × N × P fertilizer application on the 100 seed weight and the yields of kernels, pods and haulm of groundnuts

The 100 seed weight

Table 3 shows the means of the 100 seed weight and the yields of kernels, pods and haulm of groundnuts. The 100 seed weight ranged from 69.67 to 102.71 g. The results of the 100 seed weights were observed to be higher in the fields supplied with Ca, N and P either singly or in combination (Table 3). The means from fields supplied with Ca, N and P either singly or in combination were all significantly different from the unfertilized treatment ($Ca_0N_0P_0$ kg ha^{-1}) which had the lowest 100 seed weight of 69.67 g. This shows that the study site was low in the applied nutrient-elements. The highest 100 seed weight of 102.7 g was observed in the field supplied with the nutrient combination of $Ca_{200} \times N_{20} \times P_{60}$ kg ha^{-1}. This is consistent with Gashti et al. (2012) who reported that the highest 100 seed weight of 71 g was obtained from the field supplied with the high rate application of 90 kg Ca ha^{-1}. The 100 kernel weight is a good measure of how successfully pod filling had occurred (Gashti et al., 2012; Baughman and Dotray, 2015) and an indication of aborted pods due to Ca deficiency (MAFF, 2002). It follows, therefore, that groundnuts responded to Ca, N and P fertilizer combinations which resulted in seeds with higher weight and according to ratings by both Baughman and Dotray (2015) and Arnold (2014), the seeds were of good-sound kernel weight. Katsaruware and Mabwe (2014) rated the 100 seed weight of 63 g as big seeds and of good-sound weight which was far much lower than the lowest seed weight of 69.67 g observed in the current study.

Table 3. The interactive effect of combining Ca, N and P fertilizer application on the 100 seed weight, and kernel, pod and haulm yields of groundnuts in Chisamba District.

Fertilizer interaction kg ha^{-1}	100 Seed weight g	Kernel t ha^{-1}	Pod	Haulm
$Ca_0 \times N_0 \times P_0$	69.67 a	1.2 a	2.5 a	1.03 a
$Ca_0 \times N_{10} \times P_0$	79.68 b c d	1.97 b	4.17 b c	1.99 b
$Ca_0 \times N_{20} \times P_0$	81.46 b c d e f	2.11 b c d	3.00 a	2.7 b c d
$Ca_0 \times N_0 \times P_{30}$	85.44 d e f g	2 b c	5 c d e f g	2.9 b c d e
$Ca_0 \times N_{10} \times P_{30}$	96.84 k l	2.48 c d e f	4.67c d e	3.03 c d e f
$Ca_0 \times N_{20} \times P_{30}$	80.75 b c d e	2.48 c d e f	4.67 c d e	3.87 f g h i j k
$Ca_0 \times N_0 \times P_{60}$	86.4 e f g h	2.27 b c d	4.83 c d e f	3.37 c d e f g h
$Ca_0 \times N_{10} \times P_{60}$	92.73 j k	3 g h i j	5.17 d e f g	4.2 h i j k l m
$Ca_0 \times N_{20} \times P_{60}$	86.84 f g h i j	2.7 e f g h i	4.67 c d e	3.7 e f g h i j
$Ca_{100} \times N_0 \times P_0$	81.15 b c d e f	1.94 b	3.17 a	2.87 b c d e
$Ca_{100} \times N_{10} \times P_0$	86.04 e f g	2.42 b c d e f	5.17 d e f g	3.03 c d e f
$Ca_{100} \times N_{20} \times P_0$	92.29 h i j k	2.83 f g h i j	4.67 c d e	4.03 g h i j k l
$Ca_{100} \times N_0 \times P_{30}$	86.7 e f g h i	3.07 h i j	6.17 h i k	4.7klmn
$Ca_{100} \times N_{10} \times P_{30}$	95.08 k	2.91 f g h i j	4.17 b c	3.37 c d e f g h
$Ca_{100} \times N_{20} \times P_{30}$	86.08 e f g	2.73 e f g h i	5 c d e f g	4.48 j k l m
$Ca_{100} \times N_0 \times P_{60}$	78 b	2.64 e f g h i	5.33 d e f g h	5.03 m n o
$Ca_{100} \times N_{10} \times P_{60}$	87.92 g h i j	3.26 j	5.83 g h i k	5.03 m n o
$Ca_{100} \times N_{20} \times P_{60}$	87.02 f g h i j	3.01 g h i j	5.33 d e f g h	5.53 n o
$Ca_{200} \times N_0 \times P_0$	79.1 b c	2.31 b c d e	3.33 a b	2.53 b c
$Ca_{200} \times N_{10} \times P_0$	85.13 d e f g	2.53 d e f g	5.17 d e f g	3.03 c d e f
$Ca_{200} \times N_{20} \times P_0$	92.54 i j k	2.83 f g h i j	5.67 f g h i	4.2 h i j k l m
$Ca_{200} \times N_0 \times P_{30}$	84.26 c d e f g	2.98 g h i j	5.83 g h i k	3.87 f g h i j k
$Ca_{200} \times N_{10} \times P_{30}$	81.27 b c d e f	2.66 e f g h i	4.17 b c	3.5 d e f g h i
$Ca_{200} \times N_{20} \times P_{30}$	84.76 c d e f g	3.07 h i j	6.33 i k	4.34 i j k l m
$Ca_{200} \times N_0 \times P_{60}$	84.82 c d e f g	2.57 d e f g h	4.5 c d	4.17 h i j k l m
$Ca_{200} \times N_{10} \times P_{60}$	84.63 c d e f g	3.12 i j	5.57 e f g h i	4.8 l m n
$Ca_{200} \times N_{20} \times P_{60}$	102.71 l	4.18 k	6.72 k	5.87 o

Key: The different letters following values in the same column indicate level of significance at $p<0.05$ by the Duncan's Multiple Range Test.

Kernel yields of groundnuts

The kernel yields ranged from 1.2 to 4.18 t ha^{-1} (Table 3). The highest kernel yields were observed in the fields supplied with $Ca_{200}N_{20}P_{60}$ kg ha^{-1} which resulted into a 248 % increase in kernel yields over the control treatment ($Ca_0N_0P_0$). The interactive effect at the intermediate level ($Ca_{100} \times N_{10} \times P_{30}$) resulted in a 127.5 % increase in kernel yields. Application of Ca and N at high level while maintaining P at intermediate level ($Ca_{200} \times N_{20} \times P_{30}$) gave a 155.8 % increase in kernel yields.

However, both these two yield increments were lower than an increase of 248 % in kernels at the treatment rate of $Ca_{200}N_{20}P_{60}$ kg ha^{-1}. This is in agreement with Kamara et al. (2011) who applied $Ca_{100}P_{40}$ kg ha^{-1} which resulted in a 50 % increase in kernel yields. The findings are also in agreement with those from Tran and Thu (2003) who reported a 59.12% increase in kernel yields when they applied 39.28 kg P ha^{-1}.

The lowest kernel yields were recorded in the control and in the fields where the interactive effects of the three fertilizers were missing. For example, results showed that low yields were observed from fields that were supplied with $Ca_{100} \times N_0 \times P_0$ (1.94 t ha^{-1}), $Ca_0 \times N_{10} \times P_0$ (1.97 t ha^{-1}) and $Ca_0 \times N_0 \times P_{30}$ (2 t ha^{-1}). It was observed that the interaction of Ca, N and P had an additive effect resulting in increased groundnut yields. Similar synergistic effects of the interactions of Ca and P on groundnuts were reported by Kamara et al. (2011).

The synergistic effect can be explained by the fact that starter N was responsible for the establishment of the crop to start fixing N_2 (FAO, 2006) critical for the vegetative growth and photosynthetic area (Marschner, 2002). Phosphorous is critical for the development of the root network (Mengel and Kirkby, 1997; Marschner, 2002; FAO, 2006; Kamara et al., 2011) to allow the crop take up more nutrients and photosynthesise efficiently (Kamara et al., 2011). While Ca is responsible for pod filling and hence minimise the number of aborted pods (MAFF, 2002; Baughman and Dotray, 2015).

Together, the interactive effect of P (root and physiological development), N (increased photosynthetic area) and Ca (pod filling) resulted into improved crop performance (Mengel and Kirkby, 1997; Marschner, 2002; FAO, 2006) and consequently increased kernel yields such as the highest yield of 4.18 t ha^{-1} obtained from the fields supplied with $Ca_{200}N_{20}P_{60}$ kg ha^{-1}.

Pod and haulm yields of groundnuts

The pod yields ranged from 2.5 to 6.72 t ha^{-1} (Table 3). Compared to all the fertilized plots, the lowest pod yields were obtained from fields supplied with N alone ($Ca_0 \times N_{20} \times P_0$) (3 t ha^{-1}) and Ca alone ($Ca_{100} \times N_0 \times P_0$) (3.17 t ha^{-1}), suggesting that the other elements were limiting. The results also showed that in fields where the Ca × N × P interactive effect was absent, low yields were obtained. Where the additive effect of combining $Ca_{200} \times N_{20} \times P_{60}$ kg ha^{-1} was present, it resulted in pod yield of 6.72 t ha^{-1} which was more than the control, $Ca_0N_0P_0$ (2.5 t ha^{-1}), by 4.22 t ha^{-1}; an increase in pod yield of 168.8%.

The current results are in line with previous studies by Gashti et al. (2012) in Iran who reported that application of 90 kg Ca ha^{-1} resulted in the pod yields of as high as 5.65 t ha^{-1}. A similar increase in pod yield resulting from Ca and P fertilizer application was also reported by Kabir et al. (2013). In the current study, the intermediate application of $Ca_{100} \times N_{10} \times P_{30}$ resulted in pod yield of 4.17 t ha^{-1}; which represented an increase in pod yields by 66.8 % as compared to the control (unfertilized) treatment). Therefore, application of Ca, N and P resulted into synergistic interaction which increased pod yields to as high as 168.8 % obtained from the fields supplied with $Ca_{200}N_{20}P_{60}$ kg ha^{-1}.

The haulm yields ranged from 1.03 to 5.87 t ha^{-1} (Table 3). The highest haulm yields were obtained from fields supplied with $Ca_{200} \times N_{20} \times P_{60}$ kg ha^{-1}. Compared to the control treatment (1.03 t ha^{-1}), the highest haulm yield obtained from the fields supplied with $Ca_{200} \times N_{20} \times P_{60}$ kg ha^{-1} was higher by 4.84 t ha^{-1}.

The response of groundnuts to the intermediate application of $Ca_{100} \times N_{10} \times P_{30}$ kg ha^{-1} resulted in haulm yields of 3.37 t ha^{-1}; which was significantly different from the highest haulm yields obtained from fields supplied with $Ca_{200} \times N_{20} \times P_{60}$ kg ha^{-1}. Compared to the control treatment ($Ca_0N_0P_0$), the haulm yield increase from the high application ($Ca_{200} \times N_{20} \times P_{60}$ kg ha^{-1}) was (5.87 t ha^{-1}) 469.90 % while at the intermediate application ($Ca_{100} \times N_{10} \times P_{30}$ kg ha^{-1}) it was (3.37 t ha^{-1}) 227.18 %.

Conclusion

The application of the fertilizer combination at the rate of 200 kg Ca ha^{-1} × 20 kg N ha^{-1} × 60 kg P ha^{-1}, resulted in an additive synergistic effect on groundnuts giving the highest kernel yield of 4.18 t ha^{-1}, pod yield of 6.72 t ha^{-1}, haulm yield of 5.87 t ha^{-1} and a high 100 seed weight of 102.7 g. It was, therefore, concluded that to obtain optimum yields of groundnuts in a low soil fertility status area, the appropriate rates of Ca, N and P combinations is $Ca_{200}N_{20}P_{60}$ kg ha^{-1}.

Conflict of interest statement

Authors declare that they have no conflict of interest.

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