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Effect of Sulfur and Calcium-Enriched Blended Mineral Fertilizers on Groundnut (*Arachis hypogaea* L.) Productivity in the Ferruginous Tropical Soils of Senegal's Groundnut Basin

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Abstract

Groundnut (*Arachis hypogaea* L.) yields are very low in Senegal due, among other factors, to low soil fertility. This study was initiated to help improve peanut productivity by evaluating the effects of mineral fertilizer blends enriched with sulfur and calcium on peanut yield and soil fertility. The experiment was conducted during the 2019 rainy season at the CNRA in Bambey and at the ISRA station in Nioro du Rip using a randomized complete block design (RCBD) with three replications. The factor studied was mineral fertilization at seven levels: F0: absolute control at 0 kg ha⁻¹, F1: 100 kg ha⁻¹ NPK 6-20-10, F1S: 100 kg ha⁻¹ NPK 6-20-10 + 4S-4CaO; F2: 150 kg ha⁻¹ NPK 6-20-10, F2S: 150 kg ha⁻¹ NPK 6-20-10 + 4S-4CaO; F3: 200 kg ha⁻¹ NPK 6-20-10; F3S: 200 kg ha⁻¹ NPK 6-20-10 + 4S-4CaO. The ANOVA results showed a significant effect of mineral fertilization on plant height, the number of nodules per plant, pod yield, and the 100 seed-weight. Treatments using mineral fertilizers enriched with sulfur and calcium were more productive than NPK 6-20-10 alone. F3S (200 kg ha⁻¹ of NPK 6-20-10 + 4S-4CaO) recorded the highest pod yields: 2,507 kg ha⁻¹ in Bambey and 2,889 kg ha⁻¹ in Nioro du Rip, representing yield increases of 37% and 29%, respectively, compared to the standard fertilizer application F2 (150 kg ha⁻¹ NPK 6-20-10). F1S and F2S recorded yield increases of 27% and 28%, respectively, compared to F2. The highest number of filled pods per plant was obtained with F3S and F2S, with values of 22.1 ± 0.98 and 20.9 ± 0.89 full pods per plant in Bambey, and 26.2 ± 1.70 and 23.9 ± 0.49 in Nioro du Rip. The 100 seed-weight followed the same trend, with values of 45.2 ± 0.37 and 44.1 ± 0.36 g for F3S and F2S, respectively, in Bambey; and 43.1 ± 1.95 and 41.4 ± 0.91 g in Nioro du Rip. Regarding soil fertility, the results showed a more pronounced decline in soil mineral content after the trial. Thus, these results could contribute to improving groundnut productivity in Senegal's groundnut basin.

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Introduction

Agriculture, the main sector in most African countries, is the primary source of livelihood for a large proportion of

households on the continent (Afristat, 2014). For several years, Sahelian countries have been facing significant climate variability, compounded by human activities that are responsible, on the one hand, for the degradation of

natural resources, soils, and agroecosystems, and, on the other hand, for declining agricultural production, which is further exacerbated by climate change (Samb, 2010). The main economic activity in sub-Saharan Africa is agriculture, but it is characterized by low productivity. This is because the soils are nutrient poor, as well as to an insufficient supply of organic or mineral nutrients (Yao Sanlé, 2015). Central and northern Senegal are the most affected by declining rainfall, with some regions recording maximum rainfall in the 1990s that was equal to or lower than the minimum levels of the 1960s (Zaouaq, 2019). In Senegal, agriculture is one of the most important sectors of economic activity, contributing 10% of the gross domestic product (GDP) and accounting for an average of about 10% of the public investment program (FAO, 2002). Consequently, a succession of national agricultural policies and strategies has reflected the political will to make agriculture a priority sector and a driver of economic growth, income, and employment (MAER, 2018). However, agriculture today faces problems related to soil nutrient depletion, caused in part by the failure to return chemical and organic nutrients to the soil when crops are harvested and exported, and in part by the loss of minerals through runoff and drainage (Diack, 1998). To mitigate this soil degradation, recommended solutions include soil amendment (organic fertilization) or mineral fertilization with NPK fertilizers enriched with secondary nutrients such as sulfur and calcium. Sulfur (S) and calcium (Ca) play an essential role in peanut growth and productivity. Sulfur is an essential component of proteins and is involved in oil synthesis. Given its high oil and protein content, the peanut has relatively high sulfur requirements. Adequate sulfur nutrition helps improve growth, biomass production, pod yield, as well as peanut oil content and yield (Dash *et al.*, 2013; Saini and Jain, 2017; Ariraman and Kalaichelvi, 2020). Calcium plays a key role in cell integrity, pollen germination, cell division, and reproductive development. Its requirements are particularly high during pod formation and filling, hence the importance of its availability in the upper soil layers where pods develop. Adequate calcium nutrition thus promotes the formation of well-filled pods and reduces certain seed abnormalities (Rao and Shaktawat, 2002; Devakumar and Giri, 1998; Dayanand and Meena, 2002). The overall objective of this study is to contribute to improving peanut productivity by enhancing soil fertility. Specifically, the study aimed to evaluate the effects of mineral fertilizer blends enriched with sulfur and calcium on peanut growth and productivity, as well as on soil physicochemical parameters in Senegal's Groundnut Basin.

Materials and Methods

Experimental site

The trial was conducted during the 2019 rainy season at two different sites: the National Center for Agronomic Research in Bambey (CNRA) and the Senegalese Institute for Agricultural Research (ISRA) station in Nioro du Rip. The CNRA in Bambey is in the heart of the peanut-growing region in the northern zone. It is in the Diourbel region, in the department of Bambey, 120 km from Dakar, with the following geographic coordinates: 14°42' north latitude and 16°28' west longitude. The Nioro du Rip station is located approximately 60 km southeast of Kaolack and 27 km from the border with the Republic of The Gambia. Its geographic coordinates are 13°45'00" north latitude and 15°48'00" west longitude. Bambey is characterized by a Sahelo-Sudanese climate with a short rainy season (June through October) and a long dry season (November through May) (ANSD, 2019). Temperatures there are extreme, with highs ranging around 40 to 41°C and lows between 19 and 20°C. Nioro has a tropical Sudanese climate, characterized by alternating dry (November to May) and wet (June to October). Temperatures are also extreme in this area, where highs reach 40°C in April and drop to 33°C in December and January, while lows range from 15°C in December to 24°C in January. Average annual rainfall from 2009 to 2019 was 557.3 mm for Bambey and 829.7 mm for Nioro. During the 2019 rainy season, Bambey recorded a cumulative rainfall of 528.5 mm and Nioro recorded 724.4 mm (ANSD, 2019). The soils in Bambey are locally known as "Dior," a type of slightly leached tropical ferruginous soil, which accounts for 80% of the cultivated land (Niane Badiane, 1993). The soils at the Nioro station are leached tropical ferruginous soils. More precisely, they represent an intermediate type between so-called "weakly ferralitic" soils and leached tropical ferruginous soils. Soil samples were collected before planting and after harvest for analysis. Samples were collected using an auger at depths of 0–20 cm and 20–40 cm. The samples were air-dried and then sieved to 2 mm for analysis at the Soil and Water Laboratory of the CNRA in Bambey. The physicochemical characteristics of the soils are presented in Table 1.

Plant Material

The Boulkouss variety, also known as Hâtive de Séfa, was used. It is a sweet variety that is susceptible to cercosporiosis and aphids but tolerant to drought; it has

short dormancy, excellent pod clustering, and good forage quality in the foliage. The plant has an erect growth habit, light pink pods, and matures 90 days after sowing, yielding 1.5 t ha⁻¹.

Experimental Design

The experimental design is a randomised complete block design with three replicates. The factor under study is mineral fertilisation at seven levels: F0: absolute control 0 kg ha⁻¹, F1: 100 kg ha⁻¹ NPK 6-20-10, F1S: 100 kg ha⁻¹ NPK 6-20-10 + 4S-4CaO; F2: 150 kg ha⁻¹ NPK 6-20-10, F2S: 150 kg ha⁻¹ NPK 6-20-10 + 4S-4CaO; F3: 200 kg ha⁻¹ NPK 6-20-10, F3S: 200 kg ha⁻¹ NPK 6-20-10 + 4S-4CaO. The trial comprised 21 sub-plots. Each sub-plot had an area of 19.5 m² and comprised 11 rows per sub-plot and 27 planting holes per row. The spacing between rows was 50 cm and between planting holes 15 cm. The distance between blocks was 1 m and between sub-plots within the same block 0.9 m.

Crop management

The previous crop was millet in Bambey and rice in Nioro du Rip. The land was ploughed using a tractor to a depth of 15 cm, followed by harrowing to break up the clods of ploughed earth. The groundnut seeds were pre-treated with an insecticide-fungicide (Momtaz) to protect them against soil-borne pathogens. Sowing was carried out manually at a rate of two seeds per hole, at a depth of 3 cm to 4 cm. In Bambey, sowing took place on 23 August 2019 and in Nioro du Rip on 10 August 2019. The row spacing was 50 cm and 15 cm between planting holes. NPK 6-20-10 and NPK 6-20-10 +4S-4CaO fertilisers were applied as a basal dressing immediately after sowing, in accordance with the treatments under study. The first manual weeding was carried out on the 15th JAS to remove weeds, followed by thinning to one plant per hole on the 16th JAS. A second weeding took place on the 30th JAS and a third on the 45th JAS.

Pesticide treatments based on Indoxan at a rate of 1 litre per hectare were applied on the 35th DAS, the 48th DAS and the 60th DAS to control insect pests. Guarding was carried out after sowing to protect the plot from seed-eating birds and rodents. Harvesting was carried out on yield plots, leaving three border rows on each side when 70 to 80 per cent of the plants had reached maturity, i.e. on the 97th day after sowing in Nioro and the 92nd day in Bambey. After harvesting, the pods and biomass were placed in envelopes and dried in an oven for 72 hours at a temperature of 70°C.

Data Collection

For growth and symbiotic parameters, the height of the main stem, the number of branches per plant and the number of nodules per plant were measured on 10 plants selected at random from each sub-plot. The height of the main stem corresponds to the length between the collar and the apex of the main stem; for the number of branches per plant, this involved counting the main branches – that is, those arising directly from the main stem – and the number of secondary branches – that is, those attached to the main branches. For yield and yield components, pod yield, haulm yield, the number of filled pods per plant and the 100 seed-weight were measured. Yields were estimated from the yield square of each sub-plot. The 100 seed-weight was obtained by taking three random samples of 100 seeds each from each yield square and then calculating the average to obtain the final weight of 100 seeds.

Data analysis

To compare the performance of the various treatments applied, the data collected were subjected to a one-way analysis of variance (ANOVA). The normality of the residuals was tested using the Shapiro-Wilk test, and the homogeneity of variances was assessed using Bartlett's test. Mean comparisons were carried out at the 5 per cent significance level using the Newman-Keuls test, which aids interpretation and helps to identify homogeneous groups. A Pearson correlation analysis was also carried out to examine the relationships between the parameters studied. All analyses were performed using the R software package.

Results and Discussion

Effect of fertilisation on soil chemical properties

Changes in the physico-chemical parameters of the soils following the trial, as a function of the different treatment rates, are recorded in the tables 2 and 3. The analysis of variance carried out on the soil chemical parameters at Bambey revealed a highly significant difference in the effect of fertilisation on EC, Available P, Ca²⁺ and CEC (Table 2). The pH was alkaline in the 0-20 cm horizon and slightly alkaline in the 20-40 cm horizon. High electrical conductivity (0-20 cm) was recorded with F2, which is the recommended rate, followed by F1S. For the 20-40 cm horizon, F1 and F1S recorded the highest electrical conductivities. Total nitrogen (TN) and calcium (Ca²⁺) contents were slightly

higher at greater depths, regardless of the dose applied. The opposite was observed for available phosphorus (AvP) and potassium (K^+). Cation exchange capacity (CEC) followed the same pattern as phosphorus and potassium. The C/N ratio, which indicates the degree of decomposition of organic matter—that is, its ability to decompose rapidly in the soil—showed that, in the 0–20 cm horizon, the decomposition of organic matter was rapid except with F3S (10.64). Decomposition was equally good in the 20–40 cm horizon. The plots treated with calcium-containing fertiliser doses recorded the lowest Ca^{2+} reserves. CEC was low at both depths, being less than 4 meq/100 g for all applied doses. There is a slight, but not significant, leaching of certain elements such as total nitrogen (TN), available phosphorus (AvP) and calcium (Ca^{2+}). (Table 2).

The analysis of variance carried out at Nioro du Rip on soil chemical parameters (Table 3) at a depth of 0–20 cm revealed a significant effect of fertilisation on EC, AvP, Ca^{2+} and CEC. Conversely, no significant effect of mineral fertilisation was observed for pH, total nitrogen (TN) at the 0–20 cm depth, K^+ at the 20–40 cm depth, or the C/N ratio. The pH is extremely acidic, ranging from very acidic to acidic at both depths. Electrical conductivity is low at both depths but slightly higher at the surface; F1S recorded the highest value, followed by F2. The concentrations of total nitrogen, available phosphorus (P/Ass) and potassium (K^+) are slightly higher at the surface than at depth, whilst the opposite is observed for calcium (Ca^{2+}) and cation exchange capacity (CEC). The C/N ratio indicates good organic matter decomposition in the 0–20 cm horizon, except on F2, where it is low due to rapid decomposition, and in the 20–40 cm horizon (C/N between 11 and 13). The lowest reserves of Ca^{2+} were recorded on the plots that had received doses of calcium-containing fertilisers. The CEC is low at both depths (< 4 meq/100 g of soil). Although pH levels were very acidic, this did not affect the utilisation of nutrients such as Ca^{2+} and K^+ compared with the absolute control (F0) in the 0–20 cm horizon. There was minimal leaching of calcium (Ca^{2+}) (Table 3).

Effect of fertilisation on growth parameters

Analysis of variance revealed that mineral fertilisation had no significant effect on the number of branches per plant or on plant height in Bambey, regardless of the dose of mineral fertiliser applied. The mean values were 5.06 ± 0.41 number per plant and 49.4 ± 3.83 cm, respectively. At Nioro du Rip, a significant effect of mineral fertilisation was observed only on plant height.

The F3S treatment recorded the tallest plant height, at 62.2 ± 4.68 cm. The lowest value was obtained with the absolute control (40.4 ± 2.85 cm). For the number of branches per plant, the mean value was 3.78 ± 0.36 (Table 4).

Effects of fertilisation on nodulation

The results of the analysis of variance showed a significant effect of mineral fertilisation ($P < 0.5$) at Nioro du Rip and a non-significant effect at Bambey ($P > 0.5$). At Bambey, the plants that received the F3S treatment produced the highest number of nodules per plant in absolute terms (67 nodules per plant). At Nioro, the same F3S rate recorded the highest number of nodules per plant (178 nodules per plant). The lowest value was recorded with the absolute control F0 (126 nodules per plant). The Nioro du Rip site achieved the highest number of nodules per plant compared with Bambey (Figure 1).

Figure 1: Number of nodules per plant in Bambey and Nioro. Means labelled with the same letter are not statistically different at the 5 per cent significance level according to the Newman-Keuls test.

Effect of fertilisation types on agronomic parameters

Yield components: The analysis of variance carried out on the number of filled pods per plant (NFP/p) and on the 100 seed-weight (100SW) revealed a highly significant difference at both sites ($P < 0.05$). The highest number of filled pods per plant was obtained with the sulphur- and calcium-enriched treatments F3S and F2S, with respective values of 22.1 ± 0.98 and 20.9 ± 0.89 filled pods per plant at Bambey, and 26.2 ± 1.70 and 23.9 ± 0.49 at Nioro du Rip. The 100 seed-weight followed the same trend, with values for F3S and F2S of 45.2 ± 0.37 and 44.1 ± 0.36 g respectively in Bambey; and 43.1 ± 1.95 and 41.4 ± 0.91 g respectively in Nioro du Rip (Table 5).

Yields: The analysis of variance carried out on the yields showed a highly significant effect of mineral fertilisation on pod yield (PYIELD) and a non-significant effect on haulm yield (HYIELD) at both sites. The highest pod yields were obtained with F3S ($2,507 \text{ kg ha}^{-1}$), F2S ($2,333 \text{ kg ha}^{-1}$) and F1S ($2,317 \text{ kg ha}^{-1}$) in Bambey, and in Nioro with F3S ($2,889 \text{ kg ha}^{-1}$), F2S ($2,771 \text{ kg ha}^{-1}$) and F3 ($2,759 \text{ kg ha}^{-1}$). For the haulm, the highest yields were obtained with F1 ($5,429 \text{ kg ha}^{-1}$) and F1S ($5,699 \text{ kg ha}^{-1}$) in Bambey, and with F2 ($4,331 \text{ kg ha}^{-1}$) and F2S ($4,481 \text{ kg ha}^{-1}$) in Nioro du Rip (Table 5).

Correlation between observed parameters

The Pearson correlation matrix indicated that, in Bambey, the number of nodules per plant (Nod/p) was significantly and positively correlated with the number of branches per plant (NB/p). The number of filled pods per plant (NFP/p) was significantly and positively correlated with the 100 seed-weight and pod yield (PYIELD). 100 seed-weight is significantly and positively correlated with PYIELD (Table 6). At Nioro du Rip, the results showed a significant and positive correlation between the number of filled pods per plant and the number of nodules per plant, the 100 seed-weight and the pod yield.

The number of nodules per plant was also significantly and positively correlated with the 100 seed-weight and pod yield. Plant height was significantly and positively correlated with haulm yield (Table 7).

Effect of fertilisation application on soil fertility

Soil analysis results showed that the application of mineral fertilisers led to a decline in soil fertility but had a positive effect on the morphological parameters measured and on groundnut yield. The fertility results indicate an extremely acidic, very acidic to acidic pH in Nioro and a slightly alkaline to alkaline pH in Bambey. The C/N ratio in Bambey is low, resulting in slow decomposition of organic matter, and the P/Ass values of the soil samples studied fall within the reference range (5–15 ppm); this result is consistent with that of [Ballot et al., \(2016a\)](#). At Nioro, this ratio showed almost no variation. The C/N ratio provides information on the decomposition of organic matter and the availability of nutrients in the soil. The Nioro site yielded the highest pod yields compared with Bambey; this can be partly explained by its C/N ratio, which falls within the range indicative of good OM decomposition (9–12), whereas at Bambey, the C/N ratio for the majority of treatments falls within the range indicative of rapid OM decomposition (7–8). At both sites a deficit in major nutrients (nitrogen, phosphorus, potassium, calcium, etc.) and in organic matter was observed after the trial – that is, after the wet season. This may be due, on the one hand, to the leaching of mineral elements into deeper soil layers by irrigation, as at both sites irrigation was used at the end of the winter growing season to allow the crop to complete its cycle; or, on the other hand, by rainwater, as the trial was set up during the winter growing season, specifically in August, which was the rainiest month at both sites. This finding is consistent with those of

[NEPAD \(2006\)](#) in a study conducted in Guinea, which highlights the effect of heavy rainfall: on the one hand, through erosion, it causes the degradation of the soil's physical properties (depth, texture and structure); and on the other hand, through infiltration, it leads to the leaching of mineral elements. [N'Guessan et al., \(2019\)](#) demonstrated that there is vertical migration of elements—particularly clay—under the influence of infiltrating water, leading to their accumulation at depth. The application of mineral fertiliser raised pH levels in Bambey, but the opposite effect occurred in Nioro, where the application of mineral fertiliser further acidified the soil. The findings from Nioro are consistent with those of [Bado et al., \(1997\)](#) and [Pieri \(1989\)](#) who demonstrated that the continuous and exclusive application of mineral fertiliser leads to soil acidification in the long term. The decline in mineral elements and organic matter mentioned above indicates that these elements were thoroughly utilised during groundnut production, which explains the yields we achieved.

Following the groundnut crop, no treatment improved the concentration of chemical elements in the soil at either of the two study sites. Indeed, these elements, which are present in ionic form, are absorbed by the plant as required, bound by soil colloids for later use, or may be transported deeper into the soil in the sandy soils at our study sites. Indeed, the 0–20 cm cultivation horizon is predominantly sandy, which may partly explain this loss of nutrients within this horizon. The soil analyses carried out revealed that the soils studied are deficient in major elements and organic matter.

Effect of fertilisation on growth parameters

The greatest plant heights were recorded in the plots that received fertiliser compared with the control plots without fertiliser application. The poor performance of the control plots without fertiliser application can be explained by the low levels of organic matter and mineral nutrients in the soil. These results are like those of [Goalbaye et al., \(2016\)](#) and [Larounga et al., \(2020\)](#). This deficiency in mineral elements can be explained by the fact that the soils have been under cultivation for many years without a strategy to maintain or improve their fertility through the application of organic amendments ([Diallo et al., 2018](#); [Gomgnimbou et al., 2019](#)). These findings are consistent with those of [Goalbaye et al., \(2016\)](#), who demonstrated that phosphorus and nitrogen stimulate groundnut growth.

Table.1 Physicochemical characteristics of the soil at the experimental site prior to seeding.

Site	Soil depth (cm)	Rep	Particle size distribution			Chemical parameters												
			Clay	Silt	Sand	pH	EC	TN	AvP	K ⁺	Ca ²⁺	Mg ²⁺	Na ⁺	CEC	OM	TC	S	C/N
			%			1/2,5	μS/cm	%	ppm	méq/100g					%			
Bambey	0-20	R1	4.49	2.22	93.3	6.90	100.1	0.026	10.762	0.197	2.588	0.249	0.183	4.464	0.58	0.334	72.07	12.81
		R2	4.62	2.34	93	7.06	90.44	0.019	9.905	0.180	2.412	0.152	0.467	4.018	0.64	0.369	79.93	19.70
		R3	4.07	3.21	92.7	7.88	79.29	0.015	9.143	0.126	2.493	0.546	0.098	4.018	0.65	0.379	81.22	24.72
	20-40	R1	8.73	2.3	89	6.61	155.8	0.020	6.190	0.118	2.567	0.714	0.073	6.027	0.43	0.241	59.28	12.13
		R2	9.21	2.11	88.7	6.68	123.9	0.043	6.702	0.147	2.823	0.094	0.199	4.688	0.50	0.290	71.74	6.82
		R3	9.4	2	88.6	7.47	106.8	0.019	6.571	0.153	2.721	0.742	0.004	8.036	0.47	0.270	45.06	14.02
Nioro	0-20	R1	4.74	4.62	90.64	6.58	30.53	0.030	9.592	0.075	0.723	0.028	0.084	1.915	0.48	0.279	47.52	9.24
		R2	4.09	3.86	92.05	5.87	28.79	0.023	7.213	0.105	1.557	0.498	0.091	3.129	0.52	0.299	81.55	12.81
		R3	3.61	3.73	92.66	5.84	63.80	0.026	18.731	0.115	0.678	0.039	0.117	1.328	0.54	0.312	71.40	12.18
	20-40	R1	11.45	4.01	84.54	5.94	22.42	0.023	12.047	0.074	1.789	0.698	0.078	2.926	0.31	0.182	90.17	7.95
		R2	10.23	3.47	86.34	4.90	29.33	0.019	7.779	0.084	1.270	0.592	0.131	2.856	0.36	0.210	72.68	10.80
		R3	5.17	4.20	90.63	5.15	25.20	0.019	15.672	0.154	1.079	0.535	0.094	2.524	0.44	0.255	73.78	13.77

EC: Electrical conductivity; TN: Total nitrogen; K⁺: Exchangeable potassium; Ca²⁺: Exchangeable calcium; CEC: Cation exchange capacity; C/N: Carbon nitrogen ratio; OM: organic matter; TC: Total carbon; S: Sulfur; Mg²⁺: exchangeable magnesium; Na⁺: Exchangeable Sodium.

Table.2 Effect of fertilizer types on soil chemical properties after the experiment at Bambeby

Soil depth	Treatment	pH	EC	TN	AvP	K ⁺	Ca ²⁺	CEC	C/N ratio
			μS/cm	%	Ppm	meq/100			%
0-20 cm	F0	8.38 ^a	76.94 ^f	0.030 ^a	5.828 ^b	0.176 ^a	2.599 ^a	3.297 ^a	7.92 ^a
	F1	8.35 ^a	87.25 ^d	0.030 ^a	8.849 ^a	0.130 ^a	2.542 ^a	3.989 ^a	8.53 ^a
	F1S	8.26 ^a	95.27 ^b	0.027 ^a	7.986 ^a	0.142 ^a	1.944 ^a	3.538 ^a	8.75 ^a
	F2	8.18 ^a	112.9 ^a	0.032 ^a	8.418 ^a	0.185 ^a	2.375 ^a	3.972 ^a	7.92 ^a
	F2S	8.25 ^a	90.11 ^c	0.027 ^a	8.418 ^a	0.157 ^a	1.836 ^a	3.312 ^a	8.80 ^a
	F3	8.29 ^a	72.84 ^g	0.022 ^a	6.691 ^b	0.124 ^a	1.959 ^a	2.962 ^b	8.49 ^a
	F3S	8.29 ^a	78.62 ^e	0.016 ^a	7.770 ^a	0.164 ^a	0.929 ^b	2.110 ^b	10.64 ^a
	Mean	8.28	87.70	0.026	7.708	0.154	2.026	3.311	8.72
	CV	6.034	0.570	25.047	6.486	25.672	15.843	1.364	22.412
	Pr value	0.999 ^{ns}	< 2 ^{e-16} ***	0.444 ^{ns}	3.46 ^{e-05} ***	0.459 ^{ns}	0.000301***	0.000002***	0.681 ^{ns}
20-40 cm	F0	7.39 ^a	65.15 ^g	0.040 ^a	5.396 ^{bc}	0.109 ^a	2.236 ^{bc}	3.478 ^b	9.30 ^a
	F1	7.58 ^a	102.9 ^a	0.041 ^a	4.101 ^d	0.102 ^a	1.622 ^d	2.594 ^c	9.407 ^a
	F1S	7.46 ^a	91.56 ^b	0.040 ^a	6.259 ^{ab}	0.132 ^a	2.499 ^b	3.500 ^b	9.53 ^a
	F2	7.39 ^a	87.89 ^c	0.041 ^a	6.475 ^a	0.132 ^a	1.927 ^{cd}	3.045 ^b	9.67 ^a
	F2S	7.77 ^a	78.14 ^e	0.041 ^a	4.964 ^{cd}	0.104 ^a	1.701 ^d	2.846 ^b	9.47 ^a
	F3	7.48 ^a	67.08 ^f	0.038 ^a	4.964 ^{cd}	0.130 ^a	2.914 ^a	3.999 ^a	9.47 ^a
	F3S	7.72 ^a	83.22 ^d	0.039 ^a	5.396 ^{bc}	0.160 ^a	1.952 ^{cd}	2.594 ^c	9.33 ^a
	Mean	7.54	82.28	0.040	5.365	0.124	2.121	3.149	9.45
	CV	6.630	0.608	17.668	9.320	28.899	7.950	12.355	21.032
	Pr value	0.935 ^{ns}	< 2 ^{e-16} ***	0.112 ^{ns}	0.000737***	0.539 ^{ns}	2 ^{e-06} ***	0.000511***	0.1 ^{ns}

CV: Coefficient of variation; EC: Electrical conductivity; TN: Total nitrogen; K⁺: Exchangeable potassium; Ca²⁺: Exchangeable calcium; CEC: Cation exchange capacity; C/N: Carbon nitrogen ratio; AvP: Available phosphorus *; **, ***: significance levels of 5 per cent, 1 per cent and 0.1 per cent. For each column, means labelled with the same letter are not statistically different at the 5 per cent significance level according to the Newman-Keuls test.

Table.3 Effect of fertilizer types on soil chemical properties after the experiment at Nioro du Rip

Soil depth	Treatments	pH	EC	TN	AvP	K ⁺	Ca ²⁺	CEC	C/N
			μS/cm	%	ppm	meq/100			
0-20 cm	F0	5.46 ^a	24.41 ^c	0.010 ^a	7.019 ^d	0.180 ^a	1.103 ^a	2.266 ^c	9.69 ^a
	F1	4.89 ^a	23.47 ^{cd}	0.007 ^a	8.240 ^{bc}	0.143 ^{ab}	0.904 ^b	2.209 ^c	12.80 ^a
	F1S	4.96 ^a	33.39 ^a	0.015 ^a	7.134 ^{cd}	0.147 ^{ab}	0.756 ^c	2.469 ^a	9.71 ^a
	F2	4.43 ^a	33.44 ^a	0.009 ^a	10.760 ^a	0.125 ^{ab}	0.726 ^c	2.347 ^b	8.75 ^a
	F2S	4.47 ^a	26.22 ^b	0.012 ^a	7.289 ^{cd}	0.132 ^{ab}	0.910 ^b	1.457 ^f	12.72 ^a
	F3	4.78 ^a	24.23 ^c	0.012 ^a	7.597 ^{cd}	0.107 ^b	0.818 ^{bc}	1.630 ^e	11.58 ^a
	F3S	4.94 ^a	22.94 ^d	0.015 ^a	8.715 ^b	0.104 ^b	0.555 ^d	1.711 ^d	11.07 ^a
	Mean	4.85	26.87	0.011	8.108	0.121	0.825	2.013	10.93
	CV	10.335	2.024	25.517	5.866	20.145	5.311	1.885	21.480
	Pr value	0.27 ^{ns}	4.17 ^{e-13***}	0.274 ^{ns}	1.64 ^{e-06***}	0.0427 [*]	1.89 ^{e-08***}	2.61 ^{e-14***}	0.296 ^{ns}
20-40 cm	F0	4.24 ^a	21.26 ^c	0.008 ^{ab}	12.880 ^a	0.132 ^a	0.759 ^d	2.248 ^c	12.78 ^a
	F1	4.77 ^a	23.72 ^b	0.004 ^b	4.165 ^f	0.112 ^a	1.243 ^a	2.572 ^b	13.19 ^a
	F1S	4.60 ^a	26.25 ^a	0.009 ^{ab}	6.324 ^{de}	0.094 ^a	1.130 ^b	2.289 ^c	11.44 ^a
	F2	4.36 ^a	21.89 ^c	0.014 ^a	7.790 ^c	0.139 ^a	1.278 ^a	3.222 ^a	13.90 ^a
	F2S	4.90 ^a	17.61 ^c	0.015 ^a	6.941 ^{cd}	0.105 ^a	0.732 ^d	1.482 ^f	11.58 ^a
	F3	4.30 ^a	18.99 ^d	0.004 ^b	10.720 ^b	0.110 ^a	1.037 ^c	1.766 ^e	13.36 ^a
	F3S	4.82 ^a	17.65 ^c	0.004 ^b	5.553 ^e	0.105 ^a	1.041 ^c	2.160 ^d	11.58 ^a
	Mean	4.57	21.05	0.008	7.768	0.114	1.031	2.248	12.55
	CV	11.032	2.375	29.089	6.437	20.396	3.535	1.299	10.845
	Pr value	0.066 ^{ns}	2.40 ^{e-11***}	0.00245 ^{***}	5.44 ^{e-11***}	0.275 ^{ns}	7.98 ^{e-11***}	762 ^{e-16***}	0.208 ^{ns}

CV: Coefficient of variation; EC: Electrical conductivity; TN: Total nitrogen; K⁺: Exchangeable potassium; Ca²⁺: Exchangeable calcium; CEC: Cation exchange capacity; C/N: Carbon nitrogen ratio; AvP: Available phosphorus *, **, ***: significance levels of 5 per cent, 1 per cent and 0.1 per cent. For each column, means labelled with the same letter are not statistically different at the 5 per cent significance level according to the Newman-Keuls test.

Table.5 Effect of fertilisation on the number of full pods per plant, the weight of 100 seeds, and the yield of pods and foliage of groundnuts in Bambey and Nioro du Rip.

Treatments	NFP/p (g)		100SW (g)		PYIELD (kg ha ⁻¹)		HYIELD (kg ha ⁻¹)	
	Bambey	Nioro	Bambey	Nioro	Bambey	Nioro	Bambey	Nioro
F0	13.6±3.42 ^d	14.0±0.59 ^d	37.6±0.84 ^d	36.3±0.86 ^e	1,261±143.59 ^d	1,429±110.08 ^e	4,058±398.33 ^a	2,323±212.22 ^a
F1	16.2±2.70 ^{cd}	15.0±0.90 ^d	40.5±0.90 ^c	38.2±1.26 ^{de}	1,586±266.26 ^{cd}	1,792±154.82 ^d	5,429±782.78 ^a	2,972±116.67 ^a
F1S	19.9±0.95 ^{abc}	18.4±2.21 ^{bcd}	43.0±0.58 ^{ab}	39.7±1.17 ^{cd}	2,317±298.39 ^a	2,467±121.27 ^{bc}	5,699±591.11 ^a	3,111±687.78 ^a
F2	17.2±2.25 ^{bcd}	17.4±2.56 ^{cd}	40.4±0.97 ^c	38.8±1.02 ^{cd}	1,824±316.53 ^{bc}	2,246±124.57 ^c	5,362±375 ^a	4,331±1089.44 ^a
F2S	20.9±0.89 ^{ab}	23.9±0.49 ^{ab}	44.1±0.36 ^{ab}	41.4±0.91 ^{ab}	2,333±297.27 ^a	2,771±16.09 ^{ab}	5,372±311.11 ^a	4,482±1323.33 ^a
F3	17.6±2.19 ^{bcd}	22.5±1.29 ^{abc}	42.4±0.65 ^{bc}	40.6±0.72 ^{bc}	2,198±251.72 ^{ab}	2,759±89.56 ^{ab}	4,989±312.78 ^a	3,231±606.11 ^a
F3S	22.1±0.98 ^a	26.2±1.70 ^a	45.2±0.37 ^a	43.1±1.95 ^a	2,507±340.95 ^a	2,889±40.42 ^a	5,422±948.33 ^a	4,262±1171.67 ^a
Mean±Ecart type	18.21±1.91	19.63±1.39	41.88±0.67	39.73±1.19	2,003.71±273.53	2,336.14±93.83	5,190.1±531.35	3,530.29±748.89
CV	7.96	10.5	1.81	2	7.6	4.95	14	33.1
Pr	1.5 ^{e-03} ***	5.8 ^{e-04} ***	6.8 ^{e-06} ***	5.2 ^{e-05} ***	2.6 ^{e-05} ***	1.4 ^{e-07} ***	0.21 ^{ns}	0.26 ^{ns}

NFP/p: Number of filled pods per plant; 100SW: 100 seed-weight; PYIELD: Pod yield; HYIELD: Haulm yield.; CV: Coefficient of variation; *, **, ***: significance levels of 5 per cent, 1 per cent and 0.1 per cent. For each column, means labelled with the same letter are not statistically different at the 5 per cent significance level according to the Newman-Keuls test.

Table.4 Effect of fertilisation on the number of branches per plant and plant height

Treatments	Number of branches per plant		Plant height (cm)	
	Bambey	Nioro	Bambey	Nioro
F1	4.87±0.2 ^a	3.33±0.31 ^a	40.5±4.05 ^a	40.4±2.85 ^b
F1	4.69±0.3 ^a	3.73±0.09 ^a	45.0±4.33 ^a	42.4±2.02 ^b
F1S	4.89±0.3 ^a	3.69±0.39 ^a	47.5±3.60 ^a	43.8±5.71 ^b
F2	5.09±0.3 ^a	3.96±0.50 ^a	51.0±3.37 ^a	55.3±2.28 ^{ab}
F2S	5.31±0.3 ^a	3.89±0.74 ^a	50.7±2.09 ^a	55.6±6.95 ^{ab}
F3	5.20±0.8 ^a	4.20±0.36 ^a	55.7±6.31 ^a	55.7±6.83 ^{ab}
F3S	5.38±0.3 ^a	3.67±0.13 ^a	55.4±3.05 ^a	62.2±4.68 ^a
Mean + Ecart-type	5.06±0.41	3.78±0.36	49.4±3.83	50.77±4.49
CV	11.1	13.31	4.18	13
Pr value	0.71	0.54	0.09	0.01*

CV: Coefficient of variation; *, **, ***: significance levels of 5 per cent, 1 per cent and 0.1 per cent. For each column, means labelled with the same letter are not statistically different at the 5 per cent significance level according to the Newman-Keuls test.

Table.6 Correlation between the parameters studied in Bambey

	NB/p	NFP/p	Nod/p	PH	100SW	PYIELD	HYIELD
NB/p	1,00						
NP/p	0,70	1,00					
Nod/p	0,76*	0,70	1,00				
PH	0,53	0,59	0,36	1,00			
100SW	0,71	0,98***	0,65	0,70	1,00		
PYIELD	0,73	0,95***	0,54	0,65	0,97***	1,00	
HYIELD	0,17	0,73	0,22	0,61	0,71	0,68	1,00

Table.7 Correlation between the parameters studied in Nioro du Rip

	NB/p	NFP/p	Nod/p	PH	100SW	PYIELD	HYIELD
NB/p	1,00						
NFP/p	0,45	1,00					
Nod/p	0,25	0,90**	1,00				
PH	0,70	0,40	0,30	1,00			
100SW	0,45	0,97***	0,94**	0,41	1,00		
PYIELD	0,64	0,94 **	0,82*	0,42	0,95**	1,00	
HYIELD	0,48	0,70	0,60	0,76*	0,73	0,71	1,00

NB/p: Number of branches per plant; NFP/p: Number of filled pods per plant; Nod/p: Number of nodules per plant; PH: Plant height; 100SW: 100 seed-weight; PYIELD: Pod yield; HYIELD: Haulm yield. *, **, ***: significance levels of 5 per cent, 1 per cent and 0.1 per cent.

Indeed, nitrogen is the most important element for plant life; it can be extracted from the air by some plants, such as groundnuts, or from the soil. It is the driving force and is used to build all the green parts of the plant that ensure its growth and survival. However, our results contradict those of [Beugre et al., \(2020\)](#), who showed that cowpea plants grown in a nitrogen-rich substrate were less developed than those grown in a nitrogen-poor substrate.

Effect of fertilisation on the number of nodules per plant

The results obtained for the number of nodules per plant showed a significant effect of mineral fertilisation at Nioro. The Nioro du Rip site also recorded the highest number of nodules per plant across all application rates. These results could be explained by the nature of the soil at the two sites. Indeed, Bambey is characterised by poorly leached tropical ferruginous soils, whilst Nioro is characterised by leached tropical ferruginous soils. At the Nioro site, the pH values are extremely acidic to very acidic, yet the number of nodules per plant is higher there than at the Bambey site, where the pH water values are slightly alkaline to alkaline; although the soils at Nioro are acidic, this did not prevent the formation of nodules in significant quantities. These results corroborate those of [Arabo \(2012\)](#), who, having studied groundnut nodulation and soil acidity in northern Cameroon, showed that on organic and peaty hydromorphic soils with a higher pH (7.00) and on weakly ferralitic soils with a lower pH (6.7) the average total number of nodules was lower at sites with a higher pH than at sites with a lower pH. The findings of [Guibert et al., \(2012\)](#) are consistent with previous results, which showed that the average number of nodules per plant is lower at sites where the soils are less acidic; consequently, the total number of nodules cannot be used as an indicator of soil acidity. Our results differ from those of [Cheng \(2003\)](#) and [Ngo Nkot et al., \(2011\)](#), who showed that an acidic environment (pH = 4.3) produces few nodules (2.3 per plant), whilst an environment with a pH of 7 produces many more nodules (8.2 per plant). Thus, soil acidity does not influence the number of nodules, but it has a negative impact on functional nodules and on nitrogenase activity ([Arabo, 2012](#)).

Effect of fertilisation on yield and yield components

The results showed that the application of the F3S rate (200 kg ha⁻¹ of NPK 6-20-10+S-4CaO) produced a pod yield of 2,507 kg ha⁻¹ in Bambey and 2,889 kg ha⁻¹ in Nioro du Rip, representing yield increases of 37 per cent

and 29 per cent respectively compared with the standard fertiliser treatment F2 (150 kg ha⁻¹ NPK 6-20-10). These results corroborate those of [Goalbaye et al., \(2016\)](#). Furthermore, at both sites, the F1S rate (100 kg ha⁻¹ of NPK 6-20-10+S-4CaO) yielded a higher yield compared with the recommended F2 rate (150 kg ha⁻¹ of NPK 6-20-10). This could be explained by the addition of two mineral elements (S, CaO) essential for the formation of groundnut pods. These results are confirmed by those of [Ollagnier & Prevot \(1957\)](#) and [Schilling et al., \(1996\)](#).

Indeed, a lack of calcium results in unfilled pods, a fragile pod shell and reduced flower fertility ([Kaboré, 1989](#)); and this was observed when counting the number of full and unfilled pods; in the plots where only NPK fertiliser was applied, the number of unfilled pods was higher than in the plots treated with NPKS-CaO. As for sulphur, it stimulates and prolongs flowering; its presence promotes chlorophyll formation and thus good plant development ([Kaboré, 1989](#)). Indeed, chemical fertilisers comprising only NPK are incomplete and lack the macronutrients (magnesium, calcium, sulphur, etc.) that the plant requires ([Horo, 2020](#)). This partly explains the high yields associated with the application of the NPKS-CaO compound fertiliser.

As regards haulm yield, the fertilised plots yielded the highest green yields compared with the control (unfertilised) plots; this is consistent with the study by [Bado \(2002\)](#), which showed that groundnut haulm yields were low when nitrogen fertiliser was not used, but higher with increases of 30 to 54 per cent following the application of NPK mineral fertiliser. Analysis of variance revealed a significant effect of the treatments on the 100 seed-weight. F3S recorded the highest weight. These results are consistent with those of [Goalbaye et al., \(2016b\)](#), who showed that an increase in pod yield is accompanied by an increase in seed weight. For the compound fertiliser, the 100 kg ha⁻¹ application rate of NPKS-CaO yielded a higher pod yield than the recommended rate (150 kg/ha of NPK) at both sites.

Consequently, this rate could be recommended to farmers; furthermore, this same rate also yielded the highest haulm yield at the Bambey site. However, based on soil analyses – specifically regarding electrical conductivity (EC) – the 100 kg ha⁻¹ dose of NPKS-CaO (F1S) ranked second at Bambey with a value of 95.27 and first at Nioro (33.99). Electrical conductivity, however, tells us whether a soil is saline or not. As this is the lowest dose but produces a high EC, it would be better to recommend the F3S dose (200 kg ha⁻¹ of NPKS-

CaO) to prevent soil salinity in the long term. Indeed, F3S showed the lowest EC, and its C/N ratio indicated better organic matter decomposition in Bambey than in Nioro. It also yielded an acceptable amount of green matter.

In conclusion, Mineral fertilisation had a significant effect on plant height and the number of nodules per plant at Nioro du Rip. Seed yield and the weight of 100 seeds were significantly affected by mineral fertilisation. Compound fertilisers enriched with sulphur and calcium were more productive than the application of NPK 6-20-10 alone. The results showed that the application of the F3S rate (200 kg ha⁻¹ of NPK 6-20-10+4S-4CaO) yielded 2,507 kg ha⁻¹ in Bambey and 2,889 kg ha⁻¹ in Nioro du Rip, representing yield increases of 37 per cent and 29 per cent respectively compared with the standard F2 fertiliser application (150 kg ha⁻¹ NPK 6-20-10). This study also revealed that the yield of the 'Hâtive de Séfa' variety could sometimes exceed the 1.5 t ha⁻¹ figure provided by the national extension services. Regarding soil fertility, the results showed that, despite the application of fertilisers enriched with sulphur and calcium, soil deficiencies were not neutralised but persisted and remained very pronounced. The content of mineral elements and organic matter decreased compared with the pre-trial situation.

Thus, these results could make a lasting contribution to improving groundnut productivity in Senegal's groundnut-basin.

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