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Application of cow manure and inorganic fertilizer in one season and carryover of effects in sesame on tropical ferruginous soils

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The aim of this research was to find whether *Sesamum radiatum* growth requires cow manure and nitrogen-phosphorus-potassium (NPK) fertilizers. We examined the survey vegetable over two growing seasons on ferruginous soil: from June to December in 2009 (Season 1) and 2010 (Season 2). We used cow manure (0, 20, 30 and 40 t·ha^{-1}) and NPK 10:10:20 (0, 50, 100 and 150 kg·ha^{-1}) during season 1 and no amendments during season 2 to determine if application of amendments would carry through to a second season as partially described by effects on soil and yield. A randomized complete block designed through three replications is performed. Parameters such as pH, Organic carbon, Nitrogen, phosphorus, exchangeable bases (Ca^{2+}, K^+, Mg^{2+}), cation exchange capacity, base saturation and yields were identified. Cow manure significantly affected height, leaves yields while NPK had a lowly significant effect on total yield, stems yield and base saturation and highly significant effect on leaves yields, sum of bases and cation exchange capacity. Both cow manure and NPK fertilizers significantly affected magnesium and organic carbon. 20 t·ha^{-1} of cow manure and 100 kg·ha^{-1} of NPK produced the best yield in the second season and our results opened up encouraging perspectives in using magnesium, organic or inorganic fertilizers for sesame growth. The outcomes provided important prerequisite for effective cultivation of the survey leafy vegetable and it is expected to be applied in research for cultivars suitable to modern planting systems and food purposes.

Key words: Amended soil, unamended soil, yield, growing seasons, leafy vegetable.

INTRODUCTION

Soil fertility issues were serious concerns in West Africa. Local farmers amended their soils with plant and green manure. These organic resources could not improve soil fertility as they were decomposed due to high temperature, torrential rainfall or high solar radiation and were insufficient in quantity to meet the requirements of

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crops on most farmlands. In tropical ferruginous soils, some incomplete weathering of primary minerals occurred alongside the predominance of kaolinite minerals. Three types of ferruginous soils are encountered in Benin: depleted tropical ferruginous soils, slightly leached tropical ferruginous soils and leached tropical ferruginous. These soils account for 65% of the total area of the country, have a low water holding capacities and various levels of nitrogen, potassium and phosphorus (Padonou et al., 2015). A low level of organic matter is usually found in ferruginous tropical soils (Cissé et al., 2016). Factors limiting agricultural use of sandy soil include nutrient deficiencies, acidity, low water storage or poor physical attribute (Boutchich et al., 2018). Farmers used to grow annual crops on this soil, but few leafy vegetables. Sesame species were adapted to tropical agro-ecological conditions, easy to cultivate and were not very demanding in terms of inputs (Watson and Eyzaguire, 2002).

The leafy vegetable sesame used in this report, *Sesamum radiatum* Schum. and Thonn, was a traditional leafy vegetable consumed by households in Benin. It has antimicrobial, anticataract and antioxidant activities (Seukep et al., 2013; Dzoyem et al., 2014); it is found in various habitats and is not an endangered species (Bedigian, 2004). The leaves and oil of this vegetable are consumed as staples food (Konan et al., 2013). The leaves contain a high level of proteins, iron, magnesium, low levels of crude fat and fiber, and moderate levels of anti-nutrients oxalate, phytic acids and tannins (Nanloh et al., 2015). This species of sesame is a neglected and underused leafy vegetable revealed in Benin by an ethno-botanical survey (Agbanpké et al., 2014, Dansi et al., 2012). Deficiencies in micronutrients such as iron iodine, zinc and vitamin A are well known to affect children and childbearing women (Bain et al., 2013). Joy et al. (2014) estimated that micronutrients deficiency risks in Africa were highest for calcium, zinc, selenium, and iodine, while the risks for copper and magnesium deficiencies were low. These deficiencies could be eliminated by changing diets to include a greater diversity of nutrient-rich foods and useful leafy vegetable. Besides, leafy vegetables are known to contribute to a healthy diet (Baldermann et al., 2016). In Sub-Saharan Africa countries, there are a wide variety of plant species that can be consumed as leafy vegetables (Lagnika et al., 2016), but half of these countries do not meet the vegetables intake of at least 400 g person^{-1} day^{-1} as advocated by the World Health Organisation (Tata-Ngome et al., 2017). Many traditional leafy vegetables were simply being lost leaving behind just a fraction of the most popular varieties of vegetables that were less nutritious and more dependent on pesticides and fertilizers (Dansi et al., 2008). These trends can have immediate consequences on the nutritional status and food security of the populations. Therefore, for their potential to be exploited to advantage there was a need to understand their growth requirement. Pour et al. (2013) reported that the growth, yield, and quality of leafy vegetable were affected significantly by organic and inorganic nutrients applied. *S. radiatum* was an important source of iron and copper (Agbanpké et al., 2015). This vegetable had a short growth cycle and produces high yields per season and was drought-tolerant adaptable to many soil types and intolerant to wet conditions (Lim, 2014). Most of the relevant studies on yield measurement were limited only to *Sesamum indicum*, one of the oldest oilseed crops cultivated worldwide (Amoo et al., 2017) and originated from Africa (Ram et al., 1990). This crop is in the same genus, *Sesamum*, as the survey leafy vegetable. Reports in literature, addressed the traditional cultural practices (Dansi et al., 2012) and genetic characterization with markers (Adéoti et al., 2011) associated with *S. radiatum* cultivation. On the other hand, a polysaccharide extracted from *S. radiatum* leaves was analysed for its binding properties in tablet formulation (Allagh et al., 2005) or as matrix formers for sustained release tablets (Nep et al., 2016). However, no information about a fertilization requirements of this sesame species is available.Whether fertilization was relevant to scale-up its production on ferruginous soils remained to be established. The proper method for optimal exploitation of our sesame species potential has to be identified.

The objectives of this study were: (1) evaluate physicochemical properties of a tropical ferruginous soil in absence of fertilization, (2) identify organic and inorganic fertilizer treatments that benefit leafy vegetable yields, and (3) assess effects of unamended soil on leafy vegetable growth.

MATERIALS AND METHODS

Survey area and soil sampling analysis

The ferruginous sandy, slightly acidic, a soil of the survey site (Table 1) subjected to a rainy season extended from April to October and a dry season from November to March was analyzed over a 2-year experimental period. The geographical location is 8°1'59" North, and 2°28'59"East. A field trial was conducted between July and December 2009 (Season 1) and 2010 (Season 2). Soil samples were collected from 20 cm depth on June (before experiment), and December (after harvesting) for both seasons and placed in a sterile plastic bag, labeled and transported to the laboratory for determination of their chemical properties. Soil particle size analysis was performed following ISO international standard of soil particle-size analysis by destroying the soil organic matter with hydrogen peroxide using the dispersing sodium agent hexametaphosphate. After drying and weighing, a physicochemical analysis was performed on air-dried soil samples. Three samplings were made before field trial and means were computed (Table 2). Analyses were based on 1:2.5 ratios for pH-water. Other measured variables were: OC identified with Walkley-Black dichromate method adapted by ANNE (AFNOR X31-109) and based on the reduction of $K_2Cr_2O_7$ and subsequent determination of the unreduced dichromate by an oxidation-reduction titration with ammonium sulfate (Landon et al., 1991). Ca^{2+}, Mg^{2+} and K^+ were

Table 1. Texture and physical properties of the tested soil.

Soil property	**Values**
Texture	Sandy
Sand content (≥0.02 mm)	89.75%
Silt content (0.002 mm-0.02 mm)	2.10%
Clay content (≤0.002 mm)	8.15%

Table 2. pH, nutrient content and some physical characteristics of the survey ferruginous soil before field trial of Season 1 in 2009.

pH-water	pH-KCl	**Total N** (%)	**OC** (%)	OC:N	**Avail P** (mg/kg)	**Total P** (mg/kg)	**Ca^{2+}** (meq/100 g)	**Mg^{2+}** (meq/100 g)	**K^{+}** (meq/100 g)	**S** (meq/100 g)	**CEC^{a}** (meq/100 g)	**V** (%)
6.74±0.37	6.15±0.08	0.07±0.02	1.02±0.06	16.07±1.39	17.3±0.53	47.78±0.78	1.28±0.39	1.12±0.09	0.39±0.00	2.79±0.01	10.33±1.09	27±0.24

[a] CEC : Cation exchange capacity.

determined by the Atomic Absorption Spectrophotometer. Total nitrogen was identified by Kjeldahl digestion (Jackson, 1958); exchangeable bases was extracted with ammonium acetate solution at pH 7 and determined by atomic-absorption spectrometric as described by Metson (1974), available phosphorus extracted with Bray I method (Bray et al., 1945), and total phosphorus as determined by Duval (1963). The granulometric analysis was determined by the method of Robinson's pipette (1922).

Yields and growth parameters assessment

Seeds supplied locally and by the "6AVG" project during 2009 were sown directly into 7 m^2 (1 × 7 m) seedbeds with 3 seeds per hole. Seedbeds, settled on ferruginous soil were covered with *Panicum maximum* grass, which after removal, was replaced with a 15 cm shade made of *Eleais guineensis* leaves. No amendments or phytosanitary treatments were applied. Seedlings were watered daily with 22 L of water. Soils of the plots were dug-up, mixed, turned, harrowed and leveled before receiving seedlings. To identify effects of amendment application time on sesame growth, NPK 10:10:20 fertilizer at 0, 50, 100 and 150 NPK kg·ha^{-1} via a double ring method and cow manure at 0, 20, 30 and 40 t·ha^{-1} rates were applied before plant establishment in season 1. For season 2, no amendments were used. Twenty-one-day-old seedlings were transferred to 80 equal-sized plots every 2 m^2, with a row to row spacing and plant to plant spacing of 1 m. After 5 days, plants were thinned to 1 seedling per hole. Each plot received 32 seedlings distributed into 4 lines, with 160,000 plants·ha^{-1}. Seedlings that did not straighten 48 h later were replaced. All plants were watered daily with 22 L of water until they were firmly established in the soil. Plots were hand weeded and hoed once weekly. For yield estimation, plants were harvested from 2 middle rows. Three harvestings were realized on 0.48 m^2 plots. The first harvesting occurred 6 weeks after transplanting and 2 others occurred at 9 WAT and 12 WAT; yields were summed for each season. Fresh leaves separated from fresh stems were weighed immediately after cutting to determine total biomass. The dry weight of leaves and stems were performed by placing samples in a forced air oven at 80°C for 72 h. Numbers of fully expanded leaves, plant height from the soil surface to the apical bud, and a number of vegetative branches containing at least 4 fully expanded leaves were collected at 2WAT and 4WAT during Season 1 and 2 to determine short-term effects of fertilization on growth. The experimental design was a randomized complete block containing 16 treatments: 0 CM (Cow manure) and 0 NPK or control, 0 CM and 50 NPK, 0 cm and 100 NPK, 0 CM and 150 NPK, 20 cm and 0 NPK, 20 CM and 100 NPK, 20 CM and 50 NPK, 20 CM and 100 NPK, 20 CM and 150 NPK, 30 CM and 0 NPK, 30 CM and 50 NPK, 30 CM and 100 NPK, 30 CM and 150 NPK, 40 CM and 0 NPK, 40 CM and 50 NPK, 40 CM and 100 NPK or 40 CM and 150 NPK.

Data were subjected to the analysis of variance of the ANOVA procedure in SAS (ver. 9.4, SAS Inc., Cary, NC. USA). For differences amongst treatments, results of statistical tests were considered statistically significant when the P value of the ANOVA procedure was less than or equal to 0.05. Interactions involving NPK and cow manure significant with the ANOVA procedure were further analyzed via 2-way analysis using least squares means and means were separated with the Least Significant Differences of Tukey's. Average was calculated for a parameter with non-significant interrelationships.

RESULTS

Description of the rainfall regime and temperature variations

The rainfall of the survey area was 1164.4 mm. Three peaks were observed: 1 peak in March (94.5 mm) and May (122.9 mm) during the long rainy season and 1 peak in August (273 mm)

Table 3. Means values of rainfall and temperatures on the experimentation site from 2009 to 2010.

Parameter	Month											
	January	February	March	April	May	June	July	August	September	October	November	December
Year 2009												
Rainfall (mm/day)	67.50	19.40	64.20	114.60	76.90	148.20	216.10	97.10	82.00	48.90	27.20	0
Temperature (°C)												
Maximum	35.50	37.20	37.30	34.10	33.70	32.20	30.70	29.10	30.50	32.30	34.60	37.20
Minimal	22.0	24.20	24.50	23.30	23.60	23.00	22.40	22.30	22.20	22.70	22.10	23.20
Year 2010												
Rainfall (mm/day)	0	0.90	94.50	69.70	122.90	80.20	99.40	273.00	227.70	152.80	43.30	0
Temperature (°C)												
Maximum	37.50	39.10	37.80	36.30	33.60	32.90	30.60	30.20	31.00	32.60	34.40	36.00
Minimal	23.50	24.60	25.40	24.90	24.10	23.80	22.70	22.40	22.50	22.70	23.00	22.00

during the small rainy season (Table 3). The lowest average rainfall was 43.3 mm·day^{-1} in November. The trials were subjected to a range of rainfall from 0 to 148.20 mm·day^{-1} during season 1 and 80.20 to 227 mm·day^{-1} during season 2. The temperature peaked on July 2009 and dropped in August, and rose again until December for season 2 (2010). Maximum monthly average values from June to December were between 29.10 and 37.20°C for Season 1 and between 30.60 and 36°C during season 2. Minimum monthly average values from June to December were between 23.00 and 23.20°C for Season 1 and between 22 and 22.70°C during Season 2. Therefore the leafy-vegetable was more watering during season 2 than in Season 1.

Effect of mineral and organic amendments on sesame yields

The interrelationships among NPK fertilizers, cow manure, and nutrient variables are assessed in Table 4a and their mean square or degrees of freedom are presented in Table 4b. In these tables, NPK fertilizers affected the total yield, leaves yield and stems yield while cow manure affected only leaves yield. The interaction between the growing seasons and CM affected the number of branches and the height of four weeks after transplanting. Interestingly, the number of branches of 4WAT was also affected by NPK fertilizers. The growing seasons affected the total yield, total leaves yield, total stem yield, two weeks and four weeks after transplanting yield, respectively. For non-significant interrelationships among growing season, cow manure and NPK fertilizers, we performed average. Therefore, for season 1, the overall averages leave values of 2WAT and 4WAT were respectively 13.31±2.11 and 33.69±4.03. Considering 4WAT, height average is 14.99±1.38 cm and the average of branches is 11.35±2.25. Conversely, in Season 2, our analysis showed that overall averages leave values of 2WAT and 4WAT were 18.49±3.27 leaves and 101.72±10.07 leaves, respectively, while the height of 4WAT was 29.29±4.30 cm. The average number of branches was 6.52±1.06.

In Table 5, of all treatments investigated, only 0 CM and 150 NPK, and 40 CM and 150 NPK had a total yield value below that of the control (0 CM and 0 NPK) at the end of Season 1. The highest total yield (23.41 t·ha^{-1}) or stems yield (8.78 t·ha^{-1}) was produced by 0 CM and 100 NPK treatment but the highest leaves yield came from 40 CM and 50 NPK (18.53 t·ha^{-1}). Relative to the control, the later treatment leaves yield increased by 53.14%. Conversely, the lowest total yield came from 40 CM and 150 NPK treatment. Here, the values reported were 17.72, 9.61 and 5.11 t·ha^{-1} for total yield, leaves yield and stem yield respectively. Interestingly, 20, 30 and 40 CM produced a close total yield rate during Season 1 that is higher than that of 150 NPK treatments but was lower than the total yield of 50 NPK or 100 NPK treatment. These results suggested a positive contribution of cow manure to sesame yield and the negative effect of NPK fertilizers at a rate of 150 kg$^{.}$ha^{-1} on the total yields. During Season 2, the treatment 20 CM and 100 NPK ensured a higher total yield (21.65 t·ha^{-1}), total leaf yield (12.75 t·ha^{-1}) and

Table 4a. Analysis of variance table for cow manure and/or NPK fertilizer and growing season's effects on height, yield of sesame and number of leaves reported on ferruginous soil.

Parameter	Yield ($t \cdot ha^{-1}$)			Growth parameters			
	Total	**Leaves**	**Stems**	**NL-2-WAT**[a]	**NL-4-WAT**	**NBra-4-WAT**	**Height-4-WAT**
Manure (M)	0.0790	<0.0060	0.2582	0.5542	0.7994	<0.0001	0.0159
NPK (F)	0.0005	<0.0001	0.0010	0.1804	0.9637	0.0008	0.3987
Season (S)	<0.0001	<0.0001	0.0004	<0.0001	<0.0001	<0.0001	<0.0001
Interactions							
M×F	0.0028	<0.0001	0.0082	0.5813	0.1261	0.7535	0.2616
S×M	0.1811	0.6820	0.2927	0.0754	0.2032	0.0209	0.0038
S×F	0.0997	0.0060	0.1406	0.1303	0.4804	0.0589	0.6108
S×M×F	0.2090	0.0981	0.7114	0.4227	0.0919	0.3350	0.3476

ns, *, **, *** not significant or significant at $P<0.05$, $P<0.01$, $P<0.001$, least squares means analysis.
NPK = NPK fertilizers.
[a] NL-2-WAT and NL-4-WAT = number of leaves 2 and 4 weeks after transplanting in Season 1 and 2.
NBra-4-WAT = number of branches 4 weeks after transplanting in Season 1 and 2.
Height-4-WAT = Plant height 4 weeks after transplanting in Season 1 and 2.

Table 4b. Mean square and degrees of freedom table for cow manure and/or NPK fertilizer and growing season's effects on height, yield of sesame and number of leaves reported on ferruginous soil.

Parameter[a]		Yield ($t \cdot ha^{-1}$)			Growth parameter			
		Total	**Leaves**	**Stems**	**NL-2-WAT**[a]	**NL-4-WAT**	**NBra-4-WAT**	**Height-4-WAT**
Manure (M)	MS	20.743	12.536	2.703	17.677	171.051	47.095	118.606
	Df	3.000	3.000	3.000	3.000	3.000	3.000	3.000
NPK (F)	MS	59.611	43.837	12.030	42.323	47.297	25.036	31.833
	Df	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Season (S)	MS	317.321	663.835	27.414	1073.814	185113.032	934.847	8222.929
	Df	1.000	1.000	1.000	1.000	1.000	1.000	1.000
Interactions								
M×F	MS	35.310	13.822	8.369	29.162	1029.851	4.367	30.952
	Df	9.000	9.000	9.000	9.000	9.000	9.000	9.000
S×M	MS	14.668	1.378	7.839	74.802	725.820	31.754	149.928
	Df	3.000	3.000	3.000	3.000	3.000	3.000	3.000
S×F	MS	38.794	34.622	3.710	60.615	382.816	23.827	18.107
	Df	3.000	3.000	3.000	3.000	3.000	3.000	3.000
S×M×F	MS	24.878	13.257	4.291	32.111	814.702	4.714	33.905
	Df	9.000	9.000	9.000	9.000	9.000	9.000	9.000

[a] MS: Mean Square, Df: degrees of freedom of Table 4 data.

Table 5. Effects of cow manure and NPK fertilizers on yields parameters during the two growing seasons.

Cow manure	**0**				**20**				**30**				**40**			
× NPK	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**
Total Yield1	17.40^{ce}	21.80^{ac}	23.40^{a}	16.60^{de}	19.20^{acd}	21.00^{ac}	22.10^{ab}	19.70^{acd}	19.10^{ace}	19.30^{acd}	19.20^{acd}	22.70^{a}	18.30^{bce}	22.90^{a}	22.30^{ab}	14.70^{e}
Yield LF1	12.10^{ce}	15.40^{ac}	15.60^{ac}	11.00^{de}	13.30^{ce}	14.80^{acd}	17.90^{ab}	13.70^{bce}	13.20^{ce}	14.20^{acd}	15.30^{acd}	14.70^{acd}	13.80^{bce}	18.50^{a}	15.30^{acd}	9.61^{e}
Yield ST1	4.94	5.46	8.78	5.50	5.87	6.22	5.64	6.01	6.37	6.35	5.48	7.99	5.12	6.17	6.98	5.11
Total Yield2	17.70	14.60	17.90	12.5	20.40	16.30	21.6	15.00	14.8	15.80	16.1	19.3	16.60	15.90	19.8	20.1
Yield LF2	11.00	9.07	10.40	7.73	11.9	9.48	12.8	8.95	8.93	9.76	9.34	11.20	9.68	9.91	11.30	11.9
Yield ST2	6.70	5.56	7.51	4.79	8.45	6.82	8.90	6.00	5.90	6.02	6.80	8.09	6.88	6.04	8.52	8.25

$^{a-e}$Means in a row without a common superscript letter differ ($P < 0.05$) as analysed by two-way ANOVA and the TUKEY test.
Total Yield1 = Total yield of Season 1, Yield LF1 = Yield leaves of season 1, Yield ST1 = Yield Stems of Season 1,
Total Yield2 = Total yield of Season 2, Yield LF2 = Yield leaves of season 2, Yield ST2 = Yield Stems of Season 2,
Total Yield = Yield leaves + Yield Stems. Yield is estimated in tons per ha (t·ha^{-1}).

Table 6. Effects of cow manure and NPK fertilizers on growth parameters during the two growing seasons.

Cow manure	**0**				**20**				**30**				**40**			
× NPK	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**
NLF-2-WAT1	10.30	13.60	11.30	11.80	14.50	13.10	13	17.90	12.10	14	13.50	15.60	9.80	12.90	16.30	13.20
NLF-2-WAT2	22.10	23.50	16.70	14.60	17.30	20.30	17.60	13.20	12.40	17.80	17.70	20	20.60	23.5	18.60	19.90
NLF-4-WAT1	28.10	32.10	35.20	31.10	31.60	37.80	36.70	33.40	30	36.50	42	38.60	28.60	31	36.50	29.80
NLF-4-WAT2	134	111	69.40	104	94.50	102	90.80	95.20	77.80	96.20	109	107	115	105	124	91.6
Nbra-4-WAT1	6.80	9.00	10.40	9.40	8.60	12	13.60	12.60	11.60	13.60	14.80	13.80	10.40	12.60	12.80	9.60
Nbra-4-WAT2	7.30	7.15	5.50	5.25	6.25	5.75	5.75	5.00	5.45	6.90	8.70	6.75	8.05	6.85	7.45	6.15
Height1	12.10^{d}	14.40^{bd}	15.80^{abc}	13.10^{cd}	14.10^{bd}	15.30^{abc}	16.50^{ab}	15.60^{abc}	14.10^{bd}	15.80^{abc}	17.60^{a}	16.30^{ab}	13.30^{cd}	15.40^{abc}	15.80^{abc}	14.10^{bd}
Height2	31.10	29.40	24.30	28.00	26.80	27.70	26.30	22.80	24.30	29.20	30.90	30.60	36.40	30.90	39.40	30.40

Values are means, n = 5 per treatment group.
$^{a-e}$Means in a row without a common superscript letter differ ($P < 0.05$) as analysed by two-way ANOVA and the TUKEY test
NL-2-WAT1 = number of leaves 2 weeks after transplanting in Season 1,
NL-4-WAT1 = number of leaves 4 weeks after transplanting in Season 1
NL-2-WAT2 = number of leaves 2 weeks after transplanting in Season 2,
NL-4-WAT2 = number of leaves 4 weeks after transplanting in Season 2
Height1 = Plant height 4 weeks after transplanting in season 1, Height2 = Plant height 4 weeks after transplanting in Season 2.

stems yield (8.90 t·ha^{-1}) of all tested treatments of our survey. Conversely, the lowest total yield (12.52 t·ha^{-1}), total leaf yield (7.73 t·ha^{-1}) and total stem yield (4.79 t·ha^{-1}) were reported for 0 CM and 150 NPK treatments. These findings confirm the negative effect NPK fertilizers at a rate of 150 kg·ha^{-1} reported previously. In addition, only the yield of 30 or 40 cm was lower than that of 100 NPK treatments. 20 CM had a total yield higher than that of 100 NPK treatments. It appears therefore that cow manure had a sustainable positive effect only at a rate of 20 t·ha^{-1}. When this

Table 7a. Analysis of variance table for cow manure and/or NPK fertilizer and growing seasons effects on physicochemical parameters measured in 0-20cm depth on ferruginous soil.

Parameter [a]	**pH water**	**pH KCl**[a]	**OC(%)**	**N(%)**	**OC:N**	**Avail. P**	**Total P**	**Ca^{2+}**	**Mg^{2+}**	**K^{+}**	**S**	**CEC**	**V**
Manure (M)	<0.0001	0.0155	<0.0001	<0.0001	0.0097	0.0018	<0.0001	<0.0001	<0.0001	0.0034	<0.0001	<0.0001	0.1087
NPK (F)	0.6153	0.1466	0.1535	0.0302	0.0184	0.9722	0.0031	0.5127	0.0004	0.1613	<0.0001	<0.0001	0.0021
Season (S)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0227	0.0024	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Interactions													
M×F	0.4369	0.3051	0.0124	<0.0001	0.0254	0.1086	0.0328	0.9968	<0.0002	0.8059	0.0009	0.1579	0.2591
M×S	0.0010	0.8378	<0.0001	<0.0001	<0.0001	0.0142	<0.0001	<0.0001	0.0491	0.0003	<0.0001	0.0058	0.0351
F×S	0.7376	0.9108	0.4662	0.0021	0.1375	0.0709	0.0002	0.9549	0.7020	0.0929	0.8829	0.1980	0.0875
M×F×S	0.9991	0.6683	0.8772	<0.0001	0.1262	0.1401	0.0086	1.0000	0.0554	0.0571	0.1348	0.1183	0.1010

ns, *, **, *** not significant or significant at P<0.05, P<0.01, P<0.001. Data are analysed as an interaction using Least Squares means and means separated with Least Significant Differences of Tukey's.
[a] KCl = potassium chloride, OC = organic carbon (percentage of total soil mass), OC:N = ratio of organic carbon to nitrogen, N = total nitrogen, Total P = total phosphorus (mq/kg), Avail.P = available P (mg/kg), Ca^{2+}: calcium ; Mg^{2+} : magnesium ; K^{+} : potassium ; CEC : Cation Exchange Capacity; S : sum of bases (meq/100g) ;V :base saturation (%); N or Total N: Total nitrogen ; Season= Interrelationships between the end of season 1, the beginning and the end of season 2. Manure = Cow manure.

rate of cow manure was combined to 100 NPK rate, the yield was raised slightly and reached 21.65 t·ha^{-1}. Moreover, 150 NPK rate had a clearly beneficial effect as its combination with 40 CM raised the total yield from 12.52 to 20.10 t·ha^{-1} while that of 20 CM and 150 NPK and 30 CM and 150 NPK was respectively 14.95 and 19.31 t·ha^{-1}.

Relationship between season, cow manure and NPK concentration

The interrelationships among physicochemical and amendment parameters were showed in Table 7a and their mean square or degrees of freedom in Table 7b. Either the growing seasons or CM affected pH-KCl. NPK fertilizers affected OC: N ratio, the sum of bases, CEC, and saturation of bases. The interaction between CM and growing seasons affected pH-water, available P, organic carbon, the carbon-to-nitrogen ratio and calcium whereas that between CM and NPK affected organic carbon and OC: N ratio. The interrelationships among the growing seasons, CM and NPK affected total nitrogen, total P.

Evolution of physicochemical properties of the soil during the cultural and intercultural period

Tables 8, 9 and 10 showed physicochemical parameters values and Figures 1 to 3 based on the table's data show the evolution of these parameters against CM combine to NPK-fertilizer assessment during the two growing seasons studied. At the end of season 1 (Table 8), the average organic carbon (OC) level of the 16 treatments was 1.24±0.49%. In Figures 1 to 3, combinations of 0 t·ha^{-1} of cow manure and 50, 100 or 150 kg·ha^{-1} of NPK will be defined as NPK treatments and those of 20, 30 or 40 t·ha^{-1} of CM with 0 kg·ha^{-1} of NPK will be considered as cow manure treatments. The remainder combinations will stand for cow manure combined to NPK rates.
Examination of Figure 1 showed for all studied parameters that combinations including 30 and 40 t·ha^{-1} of CM gave an overall level higher than the level reported in NPK treatments at the end of season 1. In Figure1A, magnesium level decreased at 50 kg·ha^{-1} of NPK rate, especially in 20 or 40 t·ha^{-1} of CM combined to NPK rates. The level stayed stable at 20 t·ha^{-1} of CM combined to NPK rates, at 100 or 150 kg·ha^{-1} of NPK rate but clearly increased in 40 t·ha^{-1} of CM combined to NPK rates. In 30 t·ha^{-1} of CM combined to NPK rates, Mg^{2+} level increased at 50 kg·ha^{-1} of NPK rate, starting with 1.92 meq/100 g, and decreased thereafter and reached 1.87 meq/100 g at 150 kg·ha^{-1} of NPK rate. Magnesium level increased in soil range from 1.34 to 2.29 times of the initial Magnesium reported before field trial in 2009. In Figure 1B, the S levels in 40 t·ha^{-1} of CM combined to NPK rates were higher than that identified in NPK treatments and increased with NPK rates. S levels in this combination were higher than S levels of 20 or 30 t·ha^{-1} of CM combined to NPK rates. In 30 t·ha^{-1} of cow manure combined to NPK rates, the S level increased at 50 kg·ha^{-1} of NPK rate, starting with

Table 7b. Mean square and degrees of freedom table for cow manure and/or NPK fertilizer and growing seasons effects on physicochemical parameters measured in 0-20cm depth on ferruginous soil.

Parameter[a]		pH water	pH KCl	OC(%)	N(%)	OC:N	Avail. P	Total P	Ca^{2+}	Mg^{2+}	K^{+}	S	CEC	V
Manure (M)	MS	1.800	0.348	1.540	0.003	57.436	228.008	10851.741	2.044	3.728	0.069	12.690	150.701	287.736
	Df	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
NPK (F)	MS	0.065	0.165	0.184	0.000	49.201	2.753	6045.759	0.089	1.026	0.022	1.862	67.506	808.608
	Df	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Season (S)	MS	10.962	1.596	2.703	0.022	213.230	148.367	5129.915	13.000	2.473	0.841	31.173	515.865	1488.957
	Df	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000	2.000
Interactions														
M×F	MS	0.110	0.107	0.288	0.001	32.409	64.900	2551.111	0.018	0.687	0.007	0.699	7.924	175.172
	Df	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000	9.000
M×S	MS	0.630	0.046	1.001	0.002	73.467	103.379	10051.914	1.418	0.377	0.072	3.233	18.928	321.067
	Df	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
F×S	MS	0.086	0.035	0.098	0.001	19.799	75.864	3851.002	0.024	0.102	0.023	0.097	8.299	256.200
	Df	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000	6.000
M×F×S	MS	0.036	0.083	0.063	0.001	17.381	53.497	1646.117	0.014	0.291	0.025	0.365	5.242	204.995
	Df	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000	18.000

[a] MS: Mean Square, Df: Degrees of freedom of the Table 7a data.

Table 8. Effects of cow manure and NPK fertilizers on phyco-chemical parameter of ferruginous soil at the end of Season 1.

Cow manure	0				20				30				40			
× NPK	0	50	100	150	0	50	100	150	0	50	100	150	0	50	100	150
	6.53	6.35	6.32	6.29	7.21	7.16	7.05	7.11	7.46	7.46	7.18	7.3	7.58	7.46	7.38	7.34
pHKCl	6.14	6.22	6.2	6.13	6.39	6.27	6.2	6.18	6.49	5.96	6.09	6.76	6.54	6.45	6.37	6.27
OC	0.48^{c}	0.59^{bc}	0.54^{bc}	0.54^{bc}	1.48^{ac}	1.37^{ac}	1.26^{ac}	1.15^{ac}	1.7^{ac}	2.1^{a}	1.27^{ac}	1.44^{ac}	1.93^{a}	1.76^{ab}	1.59^{ac}	1.43^{ac}
Mg^{2+}	0.06^{e}	0.07^{de}	0.09^{ce}	0.09^{ce}	0.07^{de}	0.08^{de}	0.10^{bce}	0.10^{bce}	0.10^{bce}	0.14^{ac}	0.06^{e}	0.14^{ac}	0.16^{a}	0.09^{bce}	0.13^{acd}	0.15^{ab}
Ca^{2+}	7.94^{ef}	7.97^{e}	6.18^{ef}	4.33^{f}	19.9^{a}	16.9^{ab}	13.2^{cd}	11.8^{cd}	17.9^{a}	12.1^{cd}	13.5^{bc}	12.4^{cd}	11.9^{cd}	18.6^{a}	12.6^{cd}	9.8^{de}
K^{+}	14.4^{g}	19^{f}	20.1^{ef}	22.9^{cf}	20.4^{ef}	21.1^{ef}	23.5^{bce}	26.5^{ac}	22.3^{def}	25.2^{acd}	24^{bce}	27.4^{ab}	23.9^{bce}	25.5^{acd}	26.6^{ac}	28.5^{a}
Total_N	97.2^{h}	143^{g}	158^{fg}	166^{ef}	112^{h}	158^{fg}	174^{df}	189^{bcd}	143^{g}	178^{df}	186^{bcde}	202^{ac}	174^{df}	181^{cde}	204^{ab}	220^{a}
CN	1.58^{b}	1.58^{b}	1.92^{ab}	1.99^{ab}	2.26^{ab}	2.12^{ab}	2.19^{ab}	2.26^{ab}	2.63^{ab}	2.7^{ab}	2.74^{ab}	2.75^{ab}	3.14^{ab}	3.2^{ab}	3.27^{a}	3.34^{a}
S	0.4^{b}	1.64^{ab}	1.73^{ab}	1.55^{ab}	2.47^{a}	1.5^{ab}	1.5^{ab}	1.55^{ab}	1.92^{ab}	2.24^{a}	1.85^{ab}	2.2^{a}	2.19^{a}	2.05^{ab}	2.24^{a}	2.56^{a}
AvailP	0.61	0.64	0.45	0.48	0.68	0.69	0.71	0.77	0.58	0.876	0.757	0.907	0.76	0.79	0.78	0.96
TotalP	2.59^{d}	3.86^{cd}	4.1^{bd}	4.01^{bd}	5.31^{abc}	4.32^{bd}	4.4^{bd}	4.58^{ad}	5.12^{abc}	5.52^{abc}	5.85^{abc}	5.65^{abc}	6.09^{abc}	6.05^{abc}	6.28^{ab}	6.85^{a}
CEC	9.8^{d}	11^{d}	11.4^{cd}	11.9^{cd}	14.1^{bc}	14.3^{bc}	15.1^{ab}	15.3^{ab}	16.5^{ab}	16.1^{ab}	17^{ab}	17.6^{a}	17.3^{a}	17.4^{a}	17.7^{a}	17.9^{a}
V	26.4^{g}	35.1^{ad}	36^{ac}	33.7^{cde}	37.6^{ab}	30.2^{f}	29.2^{fg}	29.9^{f}	31^{ef}	34.7^{bcd}	32.4^{df}	33.9^{cde}	35.2^{ad}	34.8^{bcd}	35.5^{ad}	38.3^{a}

[a-h] Means in a row without a common superscript letter differ ($P < 0.05$) as analysed by two-way ANOVA and the TUKEY test.

Table 9. Effects of cow manure and NPK fertilizers on phyco-chemical parameter of ferruginous soil at the beginning of Season 2.

Cow manure	**0**				**20**				**30**				**40**			
× NPK	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**
pHwater	6.24	6.02	6.11	6.26	6.14	6.06	6.70	6.46	6.55	6.52	6.12	6.5	6.4	6.18	6.38	6.34
pHKCl	6.18	5.9	6.01	6.09	6.07	6.01	6.51	6.4	6.42	6.41	6.05	6.45	6.3	6.12	6.23	6.21
OC	0.624	0.84	0.84	1.11	0.93	0.682	0.88	0.63	1.17	1.01	0.60	0.69	0.76	0.67	0.81	0.77
Mg^{2+}	0.84^{d}	1.59^{bd}	1.99^{bc}	1.38^{bd}	1.73^{bc}	1.97^{bc}	1.61^{bd}	2.08^{ab}	1.45^{bd}	1.26^{cd}	1.83^{bc}	2.03^{bc}	2.05^{abc}	2^{bc}	2.15^{ab}	2.85^{a}
Ca^{2+}	1.49^{b}	1.57^{ab}	1.54^{ab}	1.59^{ab}	1.55^{ab}	1.52^{ab}	1.51^{ab}	1.73^{ab}	1.56^{ab}	1.57^{ab}	1.62^{ab}	1.65^{ab}	1.75^{a}	1.72^{ab}	1.62^{ab}	1.65^{ab}
K^{+}	0.55^{df}	0.61^{bcdf}	0.49^{f}	0.65^{ade}	0.66^{ad}	0.58^{cdf}	0.56^{df}	0.62^{bcde}	0.70^{ac}	0.53^{ef}	0.67^{ad}	0.72^{ab}	0.61^{bcdf}	0.59^{cdf}	0.76^{a}	0.62^{bcde}
Total_N	0.05^{b}	0.07^{ab}	0.07^{ab}	0.06^{ab}	0.07^{ab}	0.06^{ab}	0.07^{ab}	0.06^{ab}	0.08^{a}	0.07^{ab}	0.05^{ab}	0.07^{ab}	0.06^{ab}	0.06^{ab}	0.07^{a}	0.06^{ab}
CN	13.5	11.9	12.1	18.8	13.8	11	12.3	10	14.9	14.4	11.2	10.1	11.7	12	11.2	13.8
S	2.88^{e}	3.77^{bcd}	4.02^{bcd}	3.62^{ce}	3.94^{bcd}	4.07^{bcd}	3.68^{bce}	4.43^{ac}	3.7^{bce}	3.36^{de}	4.12^{bcd}	4.4^{ac}	4.4^{ac}	4.3^{ac}	4.53^{ab}	5.12^{a}
AvailP	27.9	30.4	22.1	26.1	25	24.6	31.5	23.2	18.8	26.8	28.6	23.5	35.1	22.4	32.9	25.7
TotalP	150^{ab}	130^{b}	132^{b}	154^{ab}	168^{ab}	187^{ab}	189^{ab}	170^{ab}	240^{ab}	245^{a}	217^{ab}	176^{ab}	201^{ab}	260^{a}	194^{ab}	203^{ab}
CEC	5^{c}	6^{bc}	12^{ac}	11^{ac}	6^{bc}	10^{ac}	11^{ac}	8^{ac}	8^{ac}	9^{ac}	9^{ac}	11^{ac}	13^{ac}	9^{ac}	15.3^{ab}	16.3^{a}
V	57.6	62.8	33.5	32.9	65.7	40.7	33.4	55.4	48.3	46.9	45.8	40	33.9	47.8	30.2	32

${}^{a\text{-}g}$Means in a row without a common superscript letter differ ($P < 0.05$) as analysed by two-way ANOVA and the TUKEY test.

Table 10. Effects of cow manure and NPK fertilizers on phyco-chemical parameter of ferruginous soil at the end of Season 2.

Cow manure	**0**				**20**				**30**				**40**			
× NPK	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**	**0**	**50**	**100**	**150**
pHwater	6	6.19	6.04	6.08	6.15	6.18	6.21	6.19	6.38	6.41	6.12	6.13	6.43	6.15	6.39	6.06
pHKCl	5.81	5.78	5.81	5.92	5.77	5.79	5.99	6.01	6.14	5.76	6.04	5.89	6.27	6.01	6.18	5.89
OC	0.67	0.92	1.11	0.82	1.41	0.72	1.17	1.01	1.29	1.15	0.78	1.14	1.08	1.3	1.34	0.92
Mg^{2+}	0.89^{ef}	1.44^{bcde}	1.56^{ad}	1.32^{de}	0.77^{f}	1.52^{bcd}	1.40^{cde}	1.16^{df}	1.14^{df}	1.06^{df}	1.21^{df}	1.96^{ab}	1.94^{ac}	1.91^{ac}	1.56^{ad}	2.09^{a}
Ca^{2+}	1.48	1.5	1.52	1.58	1.52	1.55	1.54	1.67	1.55	1.53	1.47	1.62	1.61	1.62	1.57	1.57
K^{+}	0.54^{ab}	0.47^{ac}	0.51^{ac}	0.48^{ac}	0.38^{bc}	0.42^{ac}	0.42^{ac}	0.53^{ac}	0.60^{a}	0.45^{ac}	0.39^{bc}	0.42^{ac}	0.49^{ac}	0.43^{ac}	0.34^{c}	0.39^{bc}
Total_N	0.05^{b}	0.06^{ab}	0.06^{ab}	0.07^{ab}	0.06^{ab}	0.06^{ab}	0.06^{ab}	0.07^{a}	0.07^{ab}	0.06^{ab}	0.06^{ab}	0.07^{a}	0.07^{a}	0.07^{a}	0.07^{a}	0.06^{ab}
CN	12.9	16.1	17.6	12.7	21.8	12.2	18.4	14.2	20	17.7	12.1	15.6	15.1	18.2	18.3	15
S	2.91^{fg}	3.41^{bcef}	3.59^{ae}	3.38^{cef}	2.66^{g}	3.5^{aef}	3.36^{def}	3.36^{def}	3.29^{ef}	3.04^{eg}	3.08^{eg}	4^{ac}	4.04^{ab}	3.95^{acd}	3.48^{aef}	4.06^{a}
AvailP	14	16.1	18.5	27.9	21.2	18.7	23.4	20.2	36	32.4	24.3	26.6	33.6	28.5	20	19.9
TotalP	185^{ad}	189^{ad}	162^{bcd}	173^{ad}	156^{bcd}	215^{ad}	264^{a}	228^{ac}	164^{bcd}	250^{ab}	151^{cd}	145^{cd}	129^{d}	134^{cd}	156^{bcd}	183^{ad}
CEC	4^{b}	6^{ab}	10^{ab}	8.87^{ab}	7^{ab}	8^{ab}	9^{ab}	11^{ab}	8^{ab}	10^{ab}	9^{ab}	9^{ab}	8^{ab}	10^{ab}	11^{ab}	13^{a}
V	72.8^{a}	56.9^{ab}	35.9^{ab}	37.6^{ab}	38^{ab}	43.7^{ab}	37.4^{ab}	30.6^{b}	41.1^{ab}	31.8^{ab}	34.2^{ab}	44.4^{ab}	50.5^{ab}	39.5^{ab}	31.6^{b}	31.2^{b}

${}^{a\text{-}g}$Means in a row without a common superscript letter differ ($P < 0.05$) as analysed by two-way ANOVA and the TUKEY test.

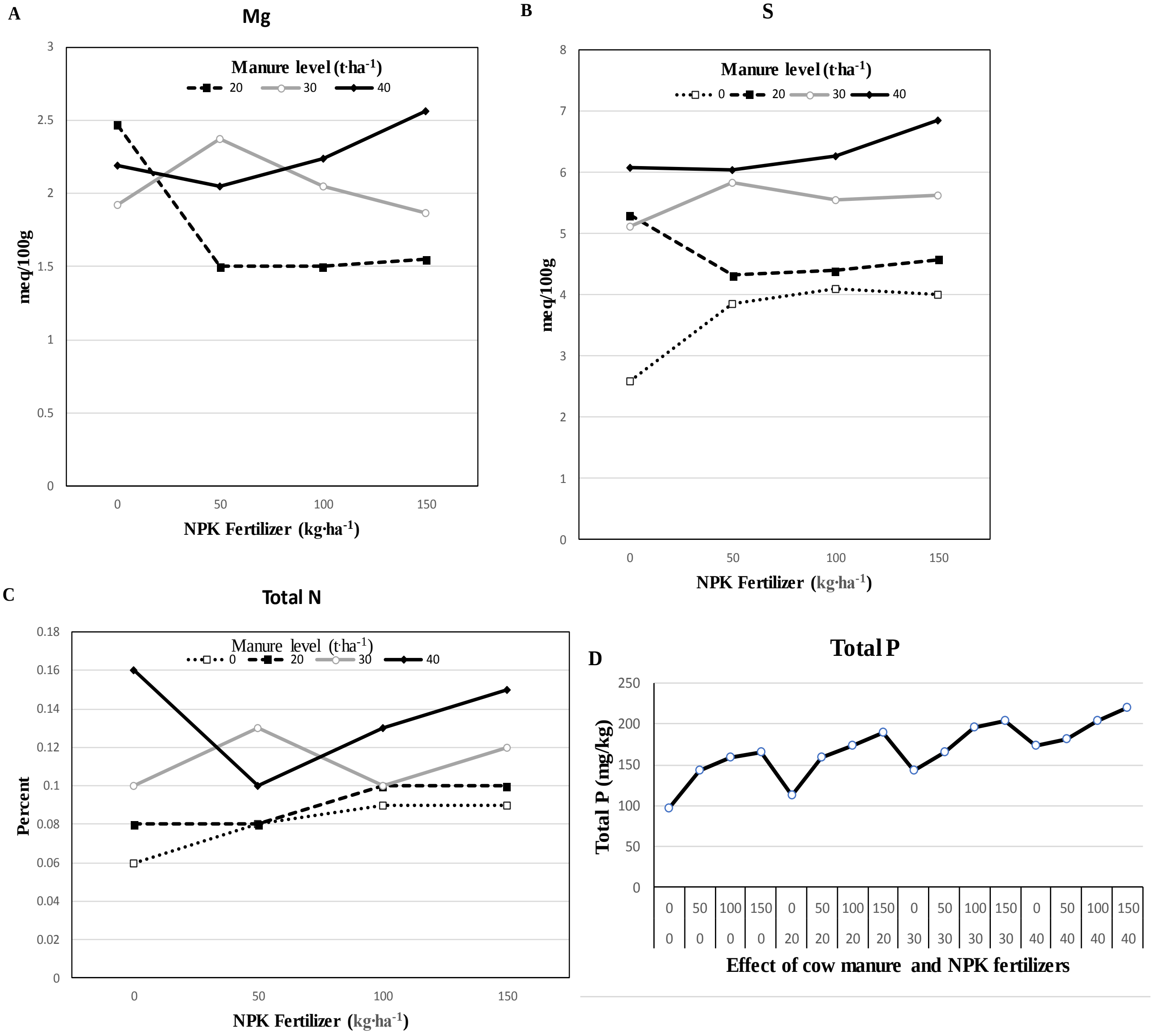

Figure 1. (A) Magnesium, (B) Sum of bases, (C) total nitrogen, (D) total phosphorus at the end of Season 1.

5.12 meq/100 g, decreased later and became almost constant from 100 to 150 kg˙ha^{-1} of NPK rate. In 20 t˙ha^{-1} of cm combined to NPK rates, S level decreased with the increase rate of NPK. We should report here that, the S level of 20 t˙ha^{-1} of CM treatment was higher than that of 20 t˙ha^{-1} of CM combined to NPK rates while in NPK treatments, the lowest S was reported from the control (2.59 meq/100 g).

In Figure1C, with starting value around 0.16% (40 t˙ha^{-1} of CM treatment), the total N content decreased for the treatment with a large number of organic restitutions (40 t˙ha^{-1} of CM combined to 50 kg˙ha^{-1} of NPK). It increased thereafter in the other treatments and reached a higher value of 0.15%. The NPK treatments evolved in the lower part of the figure, reaching a value near 0.09% with 150 kg˙ha^{-1} of NPK treatment. Interestingly, in 20 t˙ha^{-1} of CM combined to NPK rates, the total N increased with NPK rates and stabilized for 100 and 150 kg˙ha^{-1} of NPK rate. Total N level of 30 t˙ha^{-1} of CM combined to NPK rates decreased at 100 kg˙ha^{-1} of NPK rate and increased, later on, reaching 0.12% with 150 kg˙ha^{-1} of NPK rate. The levels of total N in 30 t˙ha^{-1} of CM treatment and 30 t˙ha^{-1} of CM combined to 150 kg˙ha^{-1} of NPK were similar. Total N level increased in soil range from 1.14 to 2.29 times of the initial total N reported before field trial in 2009. Total P (Figure1D) levels of the soil in 40 t˙ha^{-1} of CM combined

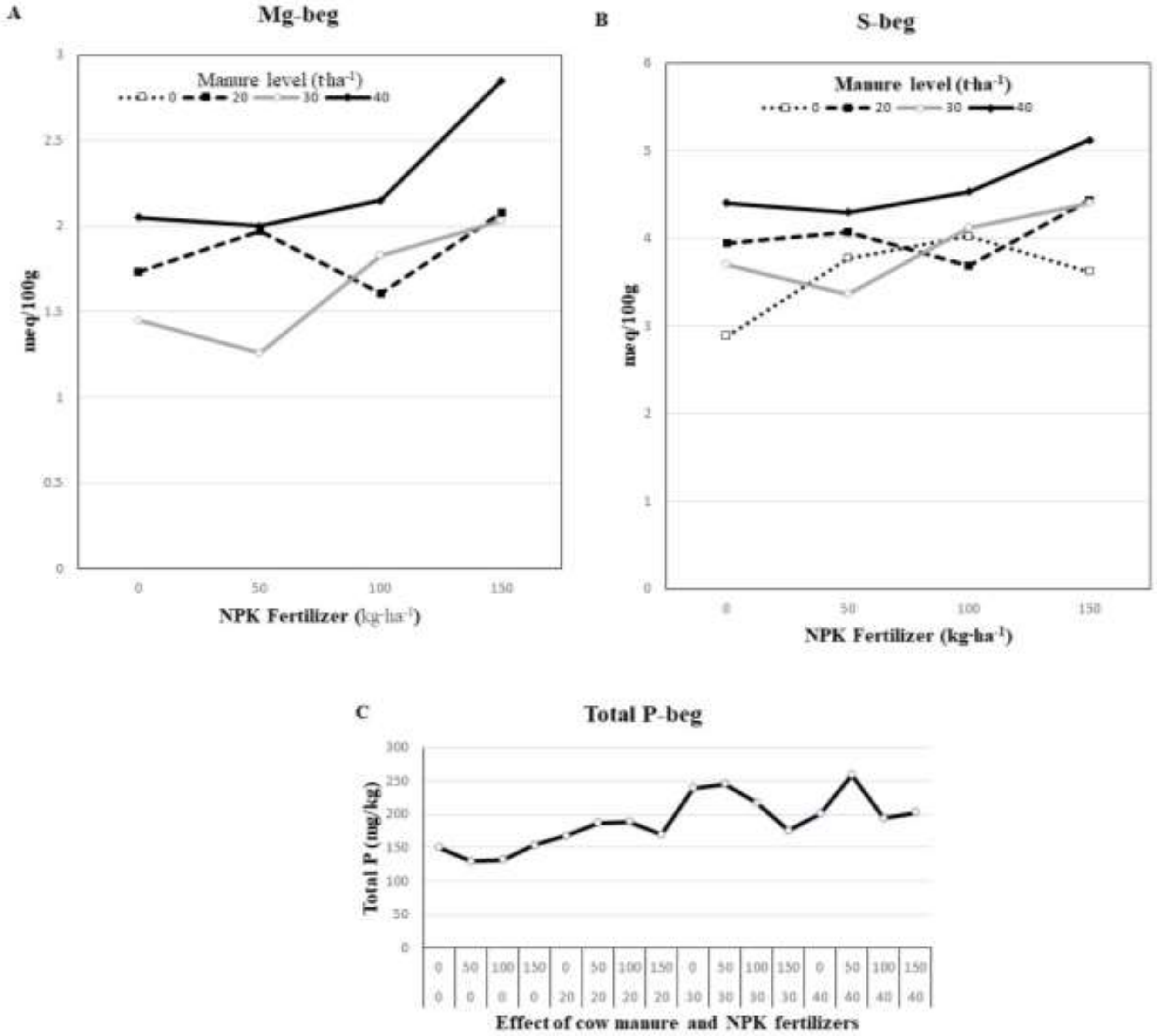

Figure 2. (A) Magnesium, (B) Sum of bases, (C) total phosphorus at the beginning of Season 2.

to 50, 100 or 150 NPK rates were higher than the levels identified in NPK treatments or cow manure treatments. Interestingly, total P levels always drop in cow manure treatments compared to the remainder treatment. In addition, the levels of this parameter increased with NPK rates. Total P level increased in soil ranged from 2.35 to 4.60 times of the initial total P reported before field trial in 2009. At the beginning of Season 2 (Table 9), total nitrogen average value of 0.06±0.01 is slightly lower than that reported before field trial (0.07%) and close to that of the control at the end of season 1 (0.06%). OC (%) average value of 0.81±0.17 was lower than that of the end of season 1 and decreased by 0.21% based on the value got before field trial. OC: N ratio average level of 12.67±2.19 was lower than OC: N levels of 20 CM and 0 NPK, 20 CM and 50 NPK, 30 CM and 17.89 NPK, 30 CM and 100 NPK or 40 CM and 50 NPK treatments at the end of season 1. Available P, the average level of 26.53±4.33 mg/kg, reported here was 1.53 times higher than that of the beginning of season 1 (17.3 mg/kg).

In Figure 2, the levels of magnesium and S in 40 t·ha^{-1} of CM combined to NPK rates were higher than those of corresponding parameters in NPK treatments. In Figure 2A, the highest amount of magnesium was reported in 40 t·ha^{-1} of CM and 150 kg·ha^{-1} of NPK. This value was 1.29 times higher than that of 40 t·ha^{-1} of CM treatment. The level of magnesium also dropped in 30 t·ha^{-1} of CM and 50 kg·ha^{-1} of NPK. It increased latter with the increase rate of NPK from 50 to 150 kg·ha^{-1}. For 20 t·ha^{-1} of CM combined to NPK rates, the level of magnesium increased alongside NPK rates but a drop was reported at 100 kg·ha^{-1} NPK rate. Magnesium level increased in soil ranged from 1.13 to 2.55 times of the initial Magnesium reported before field trial in 2009. For the S parameter (Figure 2B), the amount reported in 40 t.ha^{-1} of CM combined to NPK rates was above both that of NPK treatments and 20 or 30 t.ha^{-1} of CM combined to NPK rates. The highest amount reached is 5.12 meq/100 g. Strikingly, starting at 50 kg.ha^{-1} of NPK rate, the amount of S in 30 or 40 t.ha^{-1} of CM combined with NPK rates increased with the increase of NPK rate. Again, starting at the same rate (50 kg.ha^{-1} of NPK), the amount of S in 30 or 40 t.ha^{-1} of CM combined to 150 kg.ha^{-1} of NPK increased while that of 20 t.ha^{-1} of CM combined to 100 kg.ha^{-1} of NPK decreased and increased later at 150 kg.ha^{-1} of NPK rate. We noticed that, the levels of S in 30 or 40 t.ha^{-1} of CM treatments were higher than those of 30 or 40 t.ha^{-1} of CM combined to 50 kg.ha^{-1} of NPK , but it was lower than the level reported in 30 or 40 t.ha^{-1} of CM combined to 100 or 150 kg.ha^{-1} of NPK. In NPK treatments, the level of S in the control was the lowest S value identified (2.88 meq/100 g). The S level increased when NPK treatments moved from 50 to 100 kg.ha^{-1} but it decreased to 150 kg.ha^{-1} of NPK treatment. Total P level increased in soil ranged from 2.72 to 5.43 times of the initial total P reported before field trial in 2009 (Table 9).

In Figure 2C, total P level of 20 t.ha^{-1} of CM combined to NPK rates decreased, starting from 187.39 mg/kg. A total P level of 30 t.ha^{-1} of CM combined to NPK rates decreased, starting from 245.32 mg/kg; while that of 40 t.ha^{-1} of CM combined to NPK rates decreased and increased, later on, starting from 259.55 mg/kg. A total P level of NPK treatments increased, starting from 130.02 mg/kg. Surprisingly, total P levels of all treatments involving 100 or 150 kg.ha^{-1} of NPK combined to 20, 30 or 40 t.ha^{-1} of CM showed a decrease in the level of phosphorus compared to the remainder treatments. At the end of Season 2 (Table 10), OC: N average level of 16.12±2.89 was higher than that reported at the beginning of season 2 (12.67). OC (%) average value of 1.05±0.23 (Table 10) was higher than that noticed at the beginning of the season 2 (Table 8). It increased only by 2.94% based on OC level before field trial. The level pH-water of 30 t.ha^{-1} of CM combined to NPK rates decreased with the increase rate of NPK while that of 20 t.ha^{-1} of CM combined to NPK rates increased with the increase rate of NPK. The pH-water of 30 t.ha^{-1} of CM was 1.05 times higher than that of 30 t.ha^{-1} of CM combined to 100 kg.ha^{-1} of NPK. The highest pH-water value was reached in 40 t.ha^{-1} of CM treatment (6.43) and the lowest was reported in 40 t.ha^{-1} of CM combined to 150 kg.ha^{-1} of NPK (6.06). Obviously, relative to pH value reported before the field trial, it decreased by 4.60. In NPK treatments, pH-water level decreased with the increase rate of NPK.

In Figure 3A, magnesium level increased in 30 t.ha^{-1} of CM combined to NPK rates with the increase of NPK rate and reached a higher value of 1.96 meq/100 g. The magnesium level of 30 t.ha^{-1} of CM treatment was higher than that of 30 t.ha^{-1} of CM combined to 50 kg.ha^{-1} of NPK but lower than that 30 t.ha^{-1} of CM combined to 100 or 150 kg.ha^{-1} of NPK. The magnesium level of 20 t.ha^{-1} of CM treatment was lower than that of 20 t.ha^{-1} of CM combined to NPK rates. Here, magnesium level decreased with the increase of NPK rates. Interestingly, the magnesium level in 40 t.ha^{-1} of CM combined to NPK rates decreased with the increased NPK rates except for 40 t.ha^{-1} of CM combined to 150 kg.ha^{-1} of NPK. Surprisingly, 100 kg.ha^{-1} of NPK treatment and 40 t.ha^{-1} of CM combined to 100 kg.ha^{-1} of NPK had the same level of magnesium. Magnesium level increased in soil ranged from 1.02 to 1.87 times of the initial Magnesium reported before field trial in 2009, except for 20 t.ha^{-1} of CM treatment and 30 t.ha^{-1} of CM combined to 50 kg.ha^{-1} of NPK. In Fig.3B, S level of 20 t.ha^{-1} of CM treatment was than that of 20 t.ha^{-1} of CM combined to NPK rates. Moreover, the S of the control was lower than that identified in NPK treatments. Here, S appears to increase with the increase of NPK rates but a drop occurred in 150 kg.ha^{-1} of NPK treatment. At 150 kg.ha^{-1} of NPK rate, the S of 30 and 40 t.ha^{-1} of CM combined to NPK rates increased, starting respectively with 3.08 and 3.48 meq/100 g. It was also obvious that the S level of 40 t.ha^{-1} of CM combined to NPK rates was above that of 20 or 30 t.ha^{-1} of CM combined to NPK rates. This trend was extending to NPK treatments, except for 100 kg.ha^{-1} of NPK treatment.

In Figure 3C, total N level in both 30 t.ha^{-1} of CM combined to NPK rates increased with the increase of NPK rate. In NPK treatments, total nitrogen level increased, starting with the level reported from the control. It had the same value in 50 and 100 kg.ha^{-1} of NPK treatments, and increased in 150 kg.ha^{-1} of NPK treatment. Again, the general trend noticed, was that total N level between 50 and 100 kg.ha^{-1} of NPK rate is always constant. In addition, considering 30 t.ha^{-1} of CM treatment and 30 t.ha^{-1} of CM combined to NPK, when NPK was brought to the field, total nitrogen level dropped from 0.07 to 0.06%, became constant and increased back to 0.07%. Interestingly, total nitrogen level of 20 t.ha^{-1} of CM treatment was similar to that of 20 t.ha^{-1} of CM combined with 50 or 100 kg.ha^{-1} of NPK.

In Figure 3D, total phosphorus level in 40 t.ha^{-1} of CM combined to NPK rates increased with the increased of NPK rates while it decreased in 30 t.ha^{-1} of CM combined to NPK rates with the increase of NPK rates. In addition, the aforementioned decrease of total P levels in treatments involving 100 or 150 kg.ha^{-1} of NPK combined to 20 or 30 t.ha^{-1} of CM, reported at the beginning of season 2, were observed as well. Nonetheless, a slight increase of total P levels was reported in 100 or 150 NPK combined to 40 t.ha^{-1} of CM. The total P level of 20 t.ha^{-1} of CM combined to NPK rates reached its highest value of 263.78 mg/kg at 100 kg.ha^{-1} of NPK rate, which was 1.69 times higher than that of 20 t.ha^{-1} of cow manure treatment. Besides, the highest total P level of 249.59

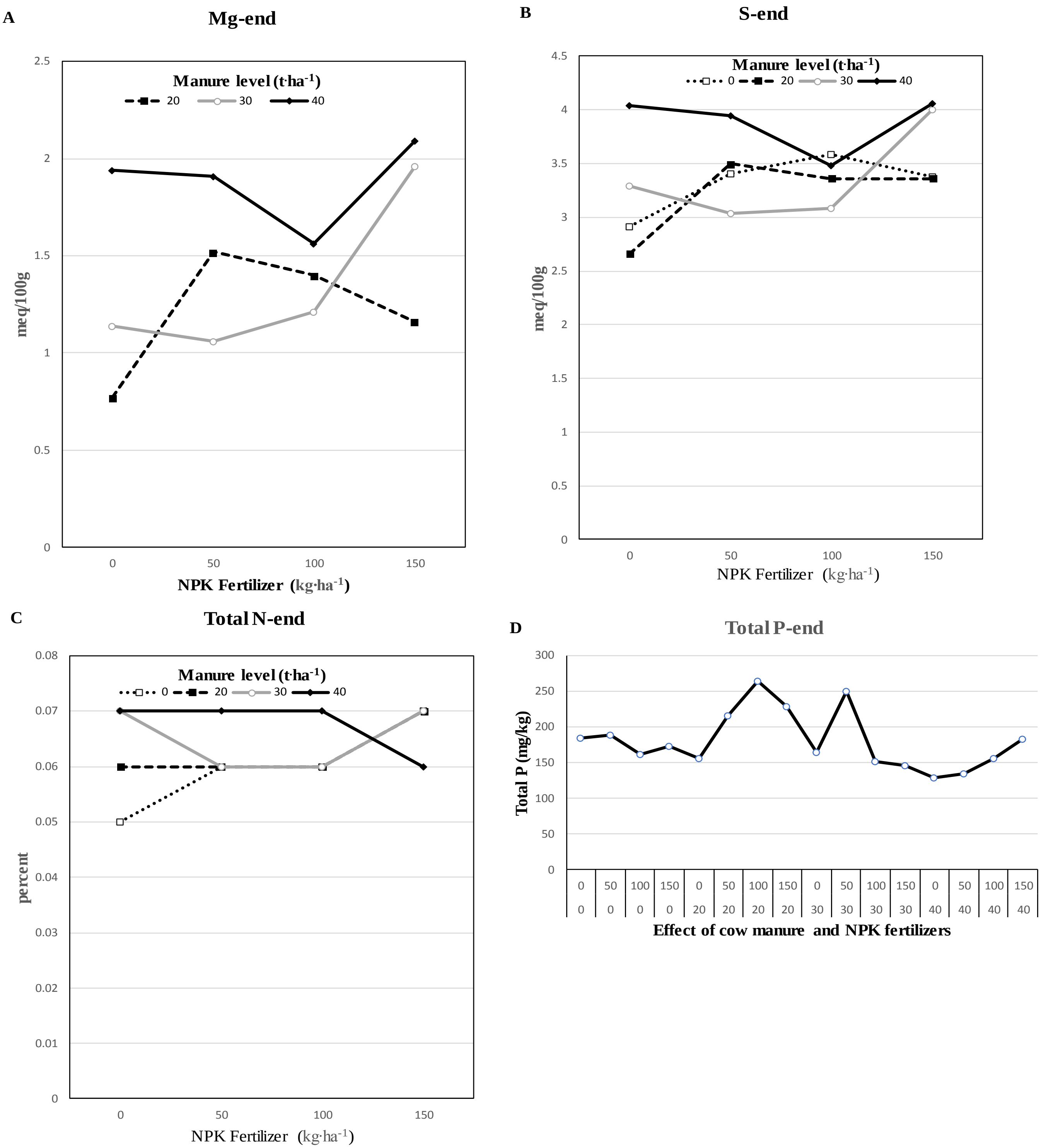

Figure 3. (A) Magnesium, (B) Sum of bases, (C) total nitrogen, (D) total phosphorus at the end of Season 2.

mg/kg reported with 30 t.ha^{-1} of CM combined to 50 kg.ha^{-1} of NPK was 1.72 times higher than the total P level of 30 t.ha^{-1} of CM combined to 150 kg.ha^{-1} of NPK but 1.52 times higher than that of 30 t.ha^{-1} of CM treatment. The total P amongst NPK treatments appears to decrease with the increasing rates of NPK. Total P level increased in soil ranged from 2.69 to 5.52 times of the initial total P identified before field trial in 2009. Taking together, all data suggesting a variable contribution of total P, magnesium and nitrogen during the growing seasons that was more prominent than the other chemicals parameters tested.

DISCUSSION

Effect of amendment on sesame yield and growth parameters

In amended context and unamended conditions, NPK fertilizers at some levels appear to affect all type of yield reported. These findings were explained because NPK at a rate of 50 or 100 kg·ha^{-1} gave a total yield higher than that of 20, 30 or 40 t·ha^{-1} of cow manure. Therefore, NPK noticeably influenced the survey sesame species only at 100 or 50 kg˙ha^{-1}. From our results, it emerged for all treatments including 0 , 20 or 40 t·ha^{-1} of cow manure combined to 0, 50 or 100 kg˙ha^{-1} of NPK, that the yield was above 16.55 t˙ha^{-1}, but with 40 t·ha^{-1} of cow manure and 150 kg˙ha^{-1} NPK, the yield was 14.72 t˙ha^{-1}. Therefore, the yield appears to be higher with NPK fertilizers than with cow manure application. The higher performance reported with sesame in NPK over cow manure shows the ease of dissolution of nutrients in the inorganic fertilizer being in a more soluble form. However, NPK at a rate of 150 kg˙ha^{-1} has both beneficial and detrimental effect on sesame yield. Indeed, the total yield level rose up from 16.55 to 19.70 or 22.68 t·ha^{-1} when 150 kg˙ha^{-1} of NPK was combined either to 20 or 30 t·ha^{-1} of cow manure. In contrast, the yield dropped when it was combined with 40 t·ha^{-1} of cow manure (14.72 t·ha^{-1}).

In unamended case, cow manure gave a yield (20.40 t·ha^{-1} for 20 and 0 kg˙ha^{-1} of NPK) higher than that of the whole NPK rate (50, 100 and 150 kg˙ha^{-1}). These results are in agreement with Natsheh and Mousa (2014)'s observations showing that plants produced by inorganic fertilizers showed relatively lower yield compared to organic materials. Industrial fertilizers do not own good characteristics of aggregating the soil particles (Seyed, 2014). This may explain the relatively lower yield obtained with 100 kg˙ha^{-1} of NPK in Season 1 compared to that of 20 t˙ha^{-1} and 100 kg˙ha^{-1} of NPK of Season 2.

Our results aligned with Xu et al. (2005)'s findings highlighted that vegetables grown with organic fertilizers resulted in a higher total yield than those grown with chemical fertilizers. Liu et al. (2016) reported that crop yields improved after addition of organic fertilizers. Nevertheless, the slight yield increase in control plot during the second year may be due to a seasonal effect.

Furthermore, the significant effect of cow manure on leaves yield combined with that of NPK fertilizers at 100 kg˙ha^{-1} appears to have a sustainable effect on leaves and stems yields and thereby improved total yield during the second growing season. Indeed, the treatment 20 t˙ha^{-1} and 100 kg˙ha^{-1} of NPK that produced the highest total yield reported in season 2 were consistent with this trend. In this report, for the overall growing seasons, yields leaves and total yield reported for 0 t˙ha^{-1} of cow manure and 100 kg˙ha^{-1} of NPK were higher when compared with those from 20 t˙ha^{-1} of cow manure and 100 kg˙ha^{-1} of NPK. In particular, it may be due to the lower availability of nutrients from organic sources in the second growing season.

As cow manure and NPK fertilizers significantly affected organic carbon or NPK fertilizers as well as cow manure affected only leaves yield we can state that fertilizers application was a necessary condition for good sesame yield. On the other hand, growing seasons affected the total yield, leaves yield and stems yield suggesting the relevancy of this parameter for sesame growth. In addition, cow manure can be used to sustain sesame yield, reduce the amount of toxic compounds produced by conventional fertilizers, hence, improving soil fertility or the quality of leafy vegetables produced and supplying more leaves for food diet. In the meantime, we can also choose an adequate type of fertilization as cow manure and NPK significantly affected both organic carbon and carbon-to-nitrogen ratio. The height and number of branches were lower in season 1 than in Season 2 suggesting the progressive release of nutrients on time either from NPK or from cow manure.

Regarding the data before experiment, we concluded, for 40 t˙ha^{-1} of cow manure and 50 kg˙ha^{-1} of NPK or 0 t˙ha^{-1} of cow manure and 100 kg˙ha^{-1} of NPK treatments of the end of Season 1 that fewer P stocks were formed and more P was available. Again, total N and S of 40 t˙ha^{-1} of cow manure combined with 50 kg˙ha^{-1} of NPK that were higher than those of 0 t˙ha^{-1} of cow manure and 100 kg.ha^{-1} of NPK appear to be conducible for more leaves yield. The increased levels of Mg^{2+} and K^{+} show to some extent the contribution of cow manure and NPK to our ferruginous soil.

Climatic effects on sesame yield

Climatic components may affect yields data of the two growing seasons (rainfall, solar radiation or temperature). Indeed, Akinyele and Osekita (2006) found that the yield of any crop depends on existing climatic and ecological factors. In our report, the yields of season 1 were subjected to 97.10, 148.00 and 216.00 mm/day of rainfall as well as 29.10 to 32.20°C maximal temperature or 22.30 to 23.00°C minimal temperature. In contrast, during season 2, yields resulted from 80.20 mm/day, 99.40 and 273.00 mm/day of rainfall with 30.20 to 32.90°C maximal temperature as well as 22.40 to 23.80°C minimal temperature. Sesame optimum temperature average is 20°C (Nyabyenda, 2005). Also, Season 2 (2010) monthly rainfall from July to November watering the soil increased from 1.59 to 3.12 times of the initial monthly rainfall reported from the same period in 2009. Therefore, we presumed rainfall and temperature variations result in a difference of yields and nutrient availability. Temperature and soil moisture influence the rate of decomposition and nutrient release (Mohammed et al., 2013, 2014). Besides, Cissé et al. (2016) found a significant correlation between the rainfall onset date and the start of the growing season on ferruginous tropical soil.

Soil nutrients fluctuation on ferruginous soil regarding the survey treatments

We found that pH-water and pH-KCl are affected by cow manure. Both parameters declined in some unamended plots. The higher soil pH level in 20, 30 or 40 t.ha^{-1} combined with 0 kg.ha^{-1} of NPK fertilizers was consistent with Braos et al. (2015)'s findings. In fact, these authors reported an increase in soil pH after applying 20 t.kg^{-1} of cattle manure as organic fertilizers. This increase of pH level was due to the presence of calcium, bicarbonate anion (HCO_3^-) buffer effect and organic acid anions in the cattle manure (Braos et al., 2015).

We also reported at the end of season 2 a ratio OC: N of 16.12 falling between 15 and 25. It occurred when cow manure was add to the soil (Hazelton and Murphy, 2007) and indicating a slow in the decomposition process of soil organic matter according to Baize (2000). Our results showed that soil carbon levels could be increased reasonably easily, remained at elevated levels with inputs but reverted back to the sustainable base level in time as its level was 1.02, 1.24, 0.81 and 1.05% from the beginning to the end of the experiment. Some parts of total N content of the soil at the end of season 2 clearly depended on NPK fertilizers. The other parts depended on 20 or 30 t.ha^{-1} of cow manure combined to 50 to 150 kg.ha^{-1} of NPK. We assuming here that the low contribution of manure treatments to N content involved a mineralization speed processes. Indeed, most N in manure is usually present in organic forms and need to be mineralized to inorganic forms ($NH4^+$ and NO_3^-) before being available for plant uptake (Gai et al., 2016). In addition, we showed that NPK fertilizers affected the sum of the bases, CEC and base saturation. The organic carbon content affected by cow manure meaning that cow manure was relevant to soil organic carbon improvement.

The variations of cations levels reported may be due to the interference of some nutrients with the uptake of a nutrient that would normally be inadequate supply. Lower content of magnesium is typically found in sandy soils (Gransee and Führs, 2013). Diouf et al. (1999) reported that traditional leafy vegetables were rich in nutrients and minerals and exhausted the soil by taking away P, K^+ and other minerals such as Mg^{2+}. These observations aligned with the loss of Mg^{2+} occurred in our survey at the end of season 2. The decrease of Mg^{2+} reported in 20 t.ha^{-1} cow manure combined to NPK rates at the end of season 2 illustrated an unbalance fertilization or antagonism between Mg^{2+}, K^+, and other soils cations. It rose up the relevancy of Mg^{2+} for sesame photosynthesis or its exhaustion by leaching and crop removal. Besides, several plant metabolic processes were affected by magnesium. From the beginning to the end of season 2, total P level was higher than available P level. Total P stocks of the end of Season 2 decreased in 30 t.ha^{-1} cow manure combined to NPK rates or 100 kg.ha^{-1} of NPK treatments; meaning that parts of total P stocks from these treatments were in available forms. It emerged that P uptake occurred only in anionic forms as H_2PO4^- and $HPO4^{2-}$, and strong P fixation was commonly observed through sorption or precipitation reactions in soils. Therefore, the fixation of P compounds by iron, aluminium oxides or soil organic matter and their degree of insolubility were responsible for the low availability of its assimilable forms for crops (Behera et al., 2014). Therefore, the remainder P accumulated in the soil and the excess amounts of P reported at the end of Season 2 for some treatments were understandable. Nonetheless, Hazelton and Murphy (2007) reported that legumes cannot grow and keep nitrogen without an appropriate level of phosphorus. Further, the formation of complexes between calcium and phosphate may restrict diffusion and adsorption of phosphate by plants. The difference in P levels, from the end of Season 1 to 2, may be due to P surface runoff, erosion and leaching. In addition, we found from our results that total phosphorus decreased in NPK treatments while increased with 40 t.ha^{-1} combined to NPK rates. It means that the presence of cow manure probably maintained an adequate supply of organic matter in soil that improved soil physical and chemical condition and led to the increase of phosphorus and CEC in 40 t.ha^{-1} combined to NPK rates. This trends probably also explained the increase of Mg^{2+} level in 30 t.ha^{-1} of cow manure combined to NPK rates at the end of Season 2. However, the small increase in Mg^{2+} contents of 40 t.ha^{-1} of cow manure combined to NPK rates was possibly due to a low content of this nutrient in cattle manure. Mantovani et al. (2017) have found a low content of Mg^{2+} in cattle manure. Ewulo (2005) reported that addition of cattle manure to soil leads to increase in soil CEC, phosphorus, and magnesium. CEC can be also affected by the positively charged ions, K^+ and $NH4^+$, provided by NPK fertilizers. In addition, available magnesium in soil increased as result of cations antagonism that exists between calcium, magnesium and potassium (Senbayram et al., 2015). Considering 0 t.ha^{-1} of cow manure combined to 100 kg.ha^{-1} of NPK and 20 t.ha^{-1} of cow manure combined to 100 kg.ha^{-1} of NPK that gave a higher yield, respectively, during Season 1 and 2, we found at the end of season 2 that total N levels were alike. For 0 t.ha^{-1} of cow manure combined to 100 kg.ha^{-1} of NPK, total P decreased while magnesium and S increased. We reported for 20 t.ha^{-1} of cow manure combined to 100 kg.ha^{-1} of NPK that total P level increased while S level decreased. Therefore, magnesium, S and total phosphorus appear to be significant for improving sesame yields. Again, cow manure and NPK fertilizers were not affecting the same parameters, except for organic carbon.

CONCLUSIONS AND PERSPECTIVES

This work shows that organic and inorganic fertilizers are relevant for sesame growth on the ferruginous soil. Further, in unamended conditions, 20 t·ha^{-1} of cow manure combined to 100 kg·ha^{-1} of NPK, improving sesame total yield and leaves, pointing out its relevancy for sustainable yield. It is therefore, recommended that 20 t·ha^{-1} of cow manure and 100 kg·ha^{-1} of NPK be used in the cultivation of *S. radiatum* and particular attention should be paid to magnesium, sum of bases and total phosphorus level of the soil for sustainable production. It will be also valuable to enhance our existing knowledge on this leafy vegetable via a genetic characterization of its diversity.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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