A Fertilizer Formulated from Crop Nutrient Removal (NPK 22-10-30) Versus 20-10-10: Yield, Soil Ph and Profitability of Black Nightshade (Solanum Scabrum Mill.) With or Without Poultry Manure in Western Cameroon

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ABSTRACT

NPK 20-10-10, the fertilizer most widely used for black nightshade (*Solanum scabrum* Mill.) in Western Cameroon, covers only about one third of the crop's potassium removal. This study compared 20-10-10 with a 22-10-30 formulated from crop nutrient removal and prepared on site (20-10-10 + urea + potassium sulphate), with or without poultry manure. A split-split-plot trial with three replicates was conducted in two environments at Dschang, each corresponding to a site × year combination: E1 (2021, Ferralsol) and E2 (2022, Andosol). It combined two manure rates (0 and 5 t/ha), five fertilizer rates (0 to 1,200 kg/ha) and two fertilizer types; fertilizer type effects were tested on the fertilized rates only (300 to 1,200 kg/ha). In E1, the manure rate × fertilizer type interaction was significant ($p = 0.033$): with 5 t/ha of manure, 22-10-30 yielded 80.1 t/ha against 66.9 t/ha for 20-10-10 (+20%), with no difference without manure. In E2, manure doubled yields (80.9 vs 39.7 t/ha) with no effect of fertilizer type on yield, but 22-10-30 left a higher soil pH-water than 20-10-10 (5.33 vs 5.11; $p = 0.005$). With the recalculated price of 22-10-30 (735 FCFA/kg), all fertilized treatments were profitable (value-cost ratio of 2.5 to 9.9). Marginal analysis identifies 1,200 kg/ha combined with manure as the most profitable rate, but this rate supplies twice the nitrogen removed by the crop. The combination of 5 t/ha of manure and 600 kg/ha of 22-10-30 is retained as a trade-off: value-cost ratio ≥ 2 in all price scenarios tested and in both environments, nitrogen supply close to crop removal, and no measured decline in soil pH.

Keywords: black nightshade, NPK 22-10-30, potassium, poultry manure, soil acidification, value-cost ratio, Western Cameroon.

INTRODUCTION

Black nightshade (*Solanum scabrum* Mill.) is a major indigenous leafy vegetable of the Western Highlands of Cameroon. Grown intensively and harvested every two weeks, it removes large amounts of nutrients from the soil. For a yield of 61 t/ha, Eone (2018) measured removals of 121 kg/ha of nitrogen, 143 kg/ha of P_2O_5 and 177 kg/ha of K_2O over four harvests.

Farmers in the region fertilize mainly with NPK 20-10-10, often without organic amendment: nearly two thirds apply nitrogen-based mineral fertilizers alone (Boukong, 2017). At the reference rate of 600 kg/ha, 20-10-10 supplies 120 kg/ha of nitrogen but only 60 kg/ha of K_2O, about one third of potassium removal. Based on these nutrient balances, a 22-10-30 formula was proposed (Eone, 2018; Kaffoua, 2019). At 600 kg/ha, it supplies 132 kg/ha of nitrogen and 180 kg/ha of K_2O, thus covering nitrogen and potassium removal. This formula had not yet been evaluated in the field.

The response to mineral fertilizers also depends on initial soil fertility and on organic matter inputs. The soils of the region, Ferralsols and Andosols, are acidic, desaturated and poor in available phosphorus (Yerima and Van

Ranst, 2005; Dahlgren et al., 2004). Exclusive use of ammonium- and urea-based fertilizers worsens their acidification (Rabeharisoa, 2004). Poultry manure, the most widely used amendment in vegetable production, improves phosphorus availability and buffers soil acidity (Hue et al., 1986; Whalen et al., 2000). Combining mineral fertilizers with organic amendments, the core principle of integrated soil fertility management, often produces a greater effect than either applied alone (Vanlauwe et al., 2010).

The objective of this study was to evaluate the effect of 22-10-30, compared with 20-10-10, at different rates and with or without poultry manure, on (i) black nightshade yield, (ii) soil pH and (iii) economic profitability. The hypothesis tested is that 22-10-30, by covering potassium removal, gives higher yields than 20-10-10 and acidifies the soil less, particularly in the presence of manure.

MATERIALS AND METHODS

Sites, soils and climatic conditions

The trial was conducted at Dschang (Western Cameroon) over two 75-day dry-season cropping cycles. The first cycle (2021; transplanted on 8 February 2021) took place at site 1 (University of Dschang Teaching and Research Farm; 5.44° N, 10.09° E; 1,407 m), a Rhodic Mollic Ferralsol (Chromic, Humic). The second (2022; transplanted on 15 October 2022) took place at site 2 (IRAD Dschang; 5.44° N, 10.08° E; 1,371 m), an Umbric Histic Aluandic Andosol (Aric) (IUSS Working Group WRB, 2022). The climate is equatorial highland, with 1,800 to 2,000 mm of rainfall per year.

The crop received a total of 587.2 mm of water in 2021, 16.6% of it through irrigation, and 645.1 mm in 2022, 96% of it through irrigation. Mean temperature was 22.6 °C and the sunshine ratio (n/N) was 0.45 in both cycles. Land suitability for black nightshade, assessed with the FAO parametric method, was rated moderate in 2021 (S2cs) and marginal in 2022 (S3csf).

Because the two cycles were conducted at different sites and at different times, each site × year combination is treated as a separate environment: E1 (site 1, 2021) and E2 (site 2, 2022). The two environments differ in soil, but also in growing season (transplanting in February vs October), water regime (16.6% vs 96% of water supplied by irrigation), land suitability and manure composition. As these factors are confounded, each environment was analysed separately.

Table 1. Characteristics of the 0–20 cm soil layer and of the poultry manure used in both cycles

Parameter	Soil 2021 (Ferralsol)	Soil 2022 (Andosol)	Manure 2021	Manure 2022
Sand (%)	70.6	63.3	–	–
Silt (%)	14.0	18.3	–	–
Clay (%)	16.0	15.3	–	–
Texture class (USDA)	Sandy loam	Sandy loam	–	–
pH-water	5.9	5.3	7.0	7.7
ΔpH (pH-KCl − pH-water)	−0.6	−1.1	–	–
Organic carbon (%)	3.83	1.68	33.04	39.35
Organic matter (%)	6.60	2.89	56.97	78.70
Total nitrogen	0.09 %	0.26 %	1.41%	3.43%

C/N	42.6	6.3	23.4	11.0
Ca, exchangeable (soil, cmol(+)/kg) or total (manure, mg/kg)	16.50	7.26	11,200	1,720
Mg (same)	4.48	1.00	9,234	1,847
K (same)	1.38	0.39	14,895	1,846
Sum of bases (cmol(+)/kg)	28.78	9.33	–	–
CEC (cmol(+)/kg)	30.35	32.70	–	–
Base saturation (%)	78.4	29.0	–	–
P Bray II (soil) or total P (manure) (mg/kg)	18.52	5.05	6,879	5,721

Values from the laboratory analysis report, except the C/N of the E1 soil and of the 2021 manure, recalculated from organic carbon and total nitrogen (soil: 3.83 / 0.09 = 42.6; manure: 33.04 / 1.41 = 23.4). Analyses: URASCE (FASA, University of Dschang), 2021 and 2022.

The E1 soil was moderately acidic, rich in organic matter and bases, and moderately supplied with phosphorus. The E2 soil was more acidic, weakly saturated (29%) and very poor in available phosphorus (5.05 mg/kg). The 2021 manure was much richer in calcium, magnesium and potassium than the 2022 manure, but contained half as much total nitrogen (1.41% vs 3.43%), which shows the high variability in composition between manure batches. The very high C/N ratio of the E1 soil (42.6), calculated from 3.83% organic carbon and 0.09% total nitrogen, reflects a low total nitrogen content relative to its organic carbon content.

Plant material and inputs

The variety SS09 ("Foumbot", broad-leaved), the most widely grown in the region, was used. Seedlings were raised for 39 days in the nursery and transplanted at the six-leaf stage. Laying-hen manure was purchased locally. Three mineral fertilizers were used: NPK 20-10-10 (20% N, 10% P_2O_5, 10% K_2O), urea (46% N) and potassium sulphate (45% K_2O). The 22-10-30 was not purchased as a formulated fertilizer: it was prepared from 20-10-10, supplemented with urea for nitrogen and with potassium sulphate for potassium. Sulphate was preferred to chloride because of the high sulphur requirement of black nightshade.

Preparation of 22-10-30 and definition of rates. For a rate Q (kg/ha) of 22-10-30, Q kg/ha of 20-10-10 was applied, supplemented with the amounts of urea and potassium sulphate needed to obtain the nutrient contents of a 22-10-30. **The rates reported for 22-10-30 (300 to 1,200 kg/ha) therefore refer to the amount of 20-10-10 used as the base, equal to the amount of 22-10-30 equivalent, and not to the mass of the final mixture**, which is about 1.49 times greater (Table 2). For each EU, the amounts of 20-10-10, urea and potassium sulphate (Table 3) were weighed and then mixed before application: the 22-10-30 was thus applied in a single operation, as a mixture. At equal rates, the two fertilizer types supply the same amount of P_2O_5 and different amounts of N and K_2O. The amount of a nutrient x supplied by Q kg/ha of a fertilizer is:

$$E_x\ (\text{kg/ha}) = Q \times \frac{t_x}{100}$$

where E_x is the amount of nutrient x (N, P_2O_5 or K_2O) and t_x its content (%) in the fertilizer. The supplement required for each nutrient is the difference between the contents of the two formulas:

$$\Delta\text{N} = Q \times \frac{22 - 20}{100} = 0.02\,Q$$

$$\Delta P_2O_5 = Q \times \frac{10 - 10}{100} = 0$$

$$\Delta K_2O = Q \times \frac{30 - 10}{100} = 0.20\,Q$$

As the P_2O_5 contents are identical (10%), no phosphorus supplement is needed. The N and K_2O supplements are converted into amounts of straight fertilizers by dividing them by the nutrient content of each fertilizer, i.e. 46% N for urea and 45% K_2O for potassium sulphate:

$$\text{Urea (kg/ha)} = \frac{\Delta N}{0.46} = \frac{0.02\,Q}{0.46} \approx 0.0435\,Q$$

$$K_2SO_4\ \text{(kg/ha)} = \frac{\Delta K_2O}{0.45} = \frac{0.20\,Q}{0.45} \approx 0.444\,Q$$

The total amount of fertilizer applied for a rate Q of 22-10-30 is therefore:

$$M_{\text{total}}\ \text{(kg/ha)} = Q + 0.0435\,Q + 0.444\,Q \approx 1.49\,Q$$

This mixture does supply the nutrients of Q kg/ha of 22-10-30: N = 0.20 Q + 0.46 × 0.0435 Q = 0.22 Q; P_2O_5 = 0.10 Q; K_2O = 0.10 Q + 0.45 × 0.444 Q = 0.30 Q. For example, for Q = 300 kg/ha: ΔN = 0.02 × 300 = 6 kg/ha, i.e. 6 / 0.46 ≈ 13 kg/ha of urea; ΔK_2O = 0.20 × 300 = 60 kg/ha, i.e. 60 / 0.45 ≈ 133 kg/ha of potassium sulphate. The amounts for each rate are given in Table 2.

Table 2. Composition of the prepared 22-10-30: amount of each component and nutrients supplied at each rate

Rate of 22-10-30, Q (kg/ha)	**20-10-10 (kg/ha)**	**Urea (kg/ha)**	**K_2SO_4 (kg/ha)**	**Mass applied (kg/ha)**	**N supplied (kg/ha)**	**P_2O_5 supplied (kg/ha)**	**K_2O supplied (kg/ha)**
300	300	13.0	133.3	446.4	66	30	90
600	600	26.1	266.7	892.8	132	60	180
900	900	39.1	400.0	1,339.1	198	90	270
1,200	1,200	52.2	533.3	1,785.5	264	120	360

Nutrient contents: 20-10-10 = 20% N, 10% P_2O_5 and 10% K_2O; urea = 46% N; potassium sulphate = 45% K_2O. The nutrients supplied are those of Q kg/ha of a 22-10-30 (0.22 Q of N, 0.10 Q of P_2O_5 and 0.30 Q of K_2O). For comparison, Q kg/ha of 20-10-10 alone supplies 0.20 Q of N, 0.10 Q of P_2O_5 and 0.10 Q of K_2O.

Final amounts applied per experimental unit. Rates expressed in kg/ha were converted into grams per EU (S_{EU} = 2.5 m²), then per row (5 rows per EU) and per plant (40 plants per EU):

$$q_{\text{EU}}\ \text{(g)} = \frac{Q\ \text{(kg/ha)} \times 1\,000 \times S_{\text{EU}}\ (\text{m}^2)}{10\,000} = \frac{Q \times 1\,000 \times 2.5}{10\,000} = 0.25\,Q$$

$$q_{\text{plant}}\ \text{(g)} = \frac{q_{\text{EU}}}{40} \qquad q_{\text{row}}\ \text{(g)} = \frac{q_{\text{EU}}}{5}$$

Thus, for 300 kg/ha of 22-10-30, each EU receives 0.25 × 300 = 75 g of 20-10-10, 0.25 × 13.0 = 3.3 g of urea and 0.25 × 133.3 = 33.3 g of potassium sulphate, i.e. 111.6 g in total (22.3 g per row and 2.8 g per plant). The manure rate of 5 t/ha corresponds to 1.25 kg per EU. The amounts for all treatments are given in Table 3.

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Table 3. Treatments T1 to T20: levels of factors A, B and C and amounts applied per experimental unit (EU of 2.5 m², 5 rows, 40 plants)

Code	A: manure (t/ha)	B: rate (kg/ha)	C: type	20-10-10 (g/EU)	Urea (g/EU)	K_2SO_4 (g/EU)	Total fertilizer (g/EU)	Manure (kg/EU)
T1	0	0	(20-10-10)	–	–	–	0	–
T2	0	0	(22-10-30)	–	–	–	0	–
T3	0	300	20-10-10	75.0	–	–	75.0	–
T4	0	300	22-10-30	75.0	3.3	33.3	111.6	–
T5	0	600	20-10-10	150.0	–	–	150.0	–
T6	0	600	22-10-30	150.0	6.5	66.7	223.2	–
T7	0	900	20-10-10	225.0	–	–	225.0	–
T8	0	900	22-10-30	225.0	9.8	100.0	334.8	–
T9	0	1,200	20-10-10	300.0	–	–	300.0	–
T10	0	1,200	22-10-30	300.0	13.0	133.3	446.4	–
T11	5	0	(20-10-10)	–	–	–	0	1.25
T12	5	0	(22-10-30)	–	–	–	0	1.25
T13	5	300	20-10-10	75.0	–	–	75.0	1.25
T14	5	300	22-10-30	75.0	3.3	33.3	111.6	1.25
T15	5	600	20-10-10	150.0	–	–	150.0	1.25
T16	5	600	22-10-30	150.0	6.5	66.7	223.2	1.25
T17	5	900	20-10-10	225.0	–	–	225.0	1.25
T18	5	900	22-10-30	225.0	9.8	100.0	334.8	1.25
T19	5	1,200	20-10-10	300.0	–	–	300.0	1.25
T20	5	1,200	22-10-30	300.0	13.0	133.3	446.4	1.25

In brackets: fertilizer type assigned to a plot that receives no mineral fertilizer; T1/T2 and T11/T12 are pairs of identical treatments (see 2.3). Fertilizers are band-applied along the 5 rows of each EU (2.4); the amount per row and per plant is obtained by dividing by 5 and by 40. Manure: 5 t/ha = 1.25 kg per EU.

Experimental design

The trial was laid out as a split-split-plot in a randomized complete block design with three replicates (Gomez and Gomez, 1984). The factors studied were:

- factor A, poultry manure rate (main plot): 0 and 5 t/ha;
- factor B, fertilizer rate (subplot): 0, 300, 600, 900 and 1,200 kg/ha;
- factor C, fertilizer type (sub-subplot): 20-10-10 and 22-10-30.

The 20 treatments were allocated to 60 experimental units (EU) of 2 m × 1.25 m (2.5 m²), spaced 0.5 m apart, for a total area of 271.25 m². The manure rate of 5 t/ha corresponds to the most profitable rate determined by Boukong (2017). The fertilizer rates bracket the reference rate of 600 kg/ha.

The 20 treatments (T1 to T20; Table 3) result from the full crossing of the three factors. Odd codes correspond to 20-10-10 and even codes to 22-10-30; T1 to T10 receive no manure and T11 to T20 receive 5 t/ha of manure. To complete the factorial, the rate B = 0 kg/ha was crossed with both fertilizer types. **T1 and T2 (no manure), as well as T11 and T12 (5 t/ha of manure), are therefore pairs of identical treatments**: they receive no mineral fertilizer and differ only by their label and their position within the subplot. These pairs were handled as follows: (i) the absolute control of the economic analysis is the mean of T1 and T2, and the "manure only" treatment is the mean of T11 and T12; (ii) the effects of fertilizer type and its interactions were tested on the fertilized rates only (see 2.6).

Crop management

Manure was incorporated two days before transplanting. Each EU received 40 plants at 25 cm × 25 cm (five rows of eight plants). Fertilizers (20-10-10 alone, or the 20-10-10 + urea + potassium sulphate mixture for 22-10-30) were band-applied along the rows on day 4 after transplanting (DAT), then covered. Three weedings (21, 42 and 63 DAT) and preventive fungicide and insecticide treatments (10, 20, 31, 46 and 61 DAT; Ridomil Gold Plus, Nordox, Cypercal 50 EC) were applied identically to all EUs.

Measured variables

Four harvests were made at 30, 45, 60 and 75 DAT, the first at 15 cm above the ground, the following ones on harvestable branches 1 cm from the main stem. Only the 18 plants of the inner rows (net plot area, NPA = 1.125 m²) were harvested. Marketable fresh yield (leaves and young stems) was weighed in the field, converted to kg/ha and summed over the four harvests:

$$Y\ (\mathrm{kg/ha}) = \frac{M_{\mathrm{NPA}}\ (\mathrm{kg}) \times 10\,000}{\mathrm{NPA}\ (\mathrm{m^2})}$$

pH-water and pH-KCl (1:2.5) were measured in each EU after the last harvest. Soil and manure analyses were carried out at URASCE following Pauwels et al. (1992).

Statistical analyses

Each environment was analysed separately by ANOVA under the split-split-plot model with three error strata (Gomez and Gomez, 1984):

$$Y_{ijkl} = \mu + R_i + A_j + \varepsilon_{a(ij)} + B_k + (AB)_{jk} + \varepsilon_{b(ijk)} + C_l + (AC)_{jl} + (BC)_{kl} + (ABC)_{jkl} + \varepsilon_{c(ijkl)}$$

where R_i is the block effect, A the manure rate, B the fertilizer rate and C the fertilizer type; ε_a (block × A; 2 df), ε_b (16 df) and ε_c (20 df) are the main-plot, subplot and sub-subplot errors. A is tested against ε_a, B and A × B against ε_b, C and its interactions against ε_c. As site and year are confounded, no combined analysis of the two environments was performed.

Two analyses were conducted for each variable. The first covers the complete design (2 × 5 × 2; 60 EUs). The second is restricted to the fertilized rates (2 × 4 × 2; 48 EUs; errors b and c with 12 and 16 df): it excludes the pairs of identical treatments T1/T2 and T11/T12, which artificially assign a fertilizer type to plots that received none, and therefore provides the valid test of the effect of fertilizer type (C) and its interactions.

Results are presented with the degrees of freedom, F values, probabilities and mean squares of each error stratum. Means of significant interactions are given with the standard error of the difference (SED) appropriate to each type of comparison (Gomez and Gomez, 1984) and, for comparisons of interest, the 95% confidence interval (95% CI) of the difference. The final pH-water of each treatment is presented with its standard error (n = 3) and the 95% CI of its deviation from the initial pH (t with 2 df). Factor means were separated with Duncan's multiple range test at the 5% level (Duncan, 1955). Analyses were performed on the data of each EU with GenStat 9.2 and R, and checked by a second, independent calculation.

Economic analysis

Profitability was assessed with the value-cost ratio (VCR), using as control the mean of the two treatments with neither manure nor fertilizer (T1 and T2) (Roy et al., 2006). The additional yield (AY) was valued at 200 FCFA/kg (VAY = AY × 200). Cost TC1 covers purchase, transport (5 FCFA/kg) and application of fertilizers and manure, and the additional harvest labour (11 FCFA per kg of AY). Unit prices are those of Table 20 of the reference thesis: 500 FCFA/kg for 20-10-10, 735 FCFA/kg for 22-10-30 prepared from 20-10-10 (price per kg of 22-10-30 equivalent, including the urea and potassium sulphate) and 125 FCFA/kg for manure. Transport of 22-10-30 is charged on the mass actually applied (1.49 Q). Application costs 25,000 FCFA/ha for fertilizers (δ_F = 1 if a fertilizer is applied) and 35,000 FCFA/ha for manure (δ_M = 1 if manure is applied):

$$\mathrm{TC}_1 = Q_{20}\,(p_{20} + 5) + Q_{22}\,(735 + 5 \times 1.49) + 5\,000\,(125 + 5)\,\delta_M + 25\,000\,\delta_F + 35\,000\,\delta_M + 11 \times \mathrm{AY}$$

Cost TC2 adds interest on the investment (2.45% per year over 78 days):

$$\mathrm{VCR} = \frac{\mathrm{VAY}}{\mathrm{TC}_2}, \qquad \mathrm{TC}_2 = \mathrm{TC}_1\left(1 + 0.0245 \times \frac{78}{365}\right)$$

A treatment is considered profitable and suitable for extension if VCR ≥ 2, adoptable with restrictions if 1.5 < VCR < 2, and rejected below that (Kaho et al., 2011). Because the VCR is a ratio, it does not show which treatment provides the highest gain. Net benefit (NB) and the marginal rate of return (MRR) were therefore calculated following marginal analysis (CIMMYT, 1988): treatments are ranked by increasing cost, those whose NB is lower than that of a less costly treatment are eliminated (dominated treatments), and moving from one treatment to the next is considered worthwhile only if the MRR is at least 100%:

$$\mathrm{NB} = \mathrm{VAY} - \mathrm{TC}_2 \qquad \mathrm{MRR}\,(\%) = \frac{\mathrm{NB}_t - \mathrm{NB}_{t-1}}{\mathrm{TC}_{2,t} - \mathrm{TC}_{2,t-1}} \times 100$$

Finally, the sensitivity of the results to prices was tested by varying the price of black nightshade (−25% and −50%), the price of mineral fertilizers (+25%), that of fertilizers and manure (+50%) and the price of 22-10-30 alone (+25%, i.e. 919 FCFA/kg), and by combining the least favourable scenario (nightshade −50%, inputs +50%). The break-even price of nightshade p*, below which a treatment no longer reaches VCR = 2, was calculated for each treatment:

$$p^*\,(\mathrm{FCFA/kg}) = \frac{2 \times \mathrm{TC}_2}{\mathrm{AY}}$$

RESULTS

Marketable fresh yield

The full results of both analyses (df, F, probabilities and error mean squares) are given in Tables 4 and 5. In both environments, fertilizer rate had a very highly significant effect on cumulative yield ($p < 0.001$). In E1, the A × C interaction was significant both in the complete design ($F = 4.45$; $p = 0.048$) and on the fertilized rates only ($F = 5.48$; $p = 0.033$). In E2, manure rate ($F = 64.6$; $p = 0.015$) and the A × B interaction ($F = 5.91$; $p = 0.004$) were significant, with no effect of fertilizer type ($p = 0.802$; $p = 0.756$ on the fertilized rates). The CV of error c

was 18.3% (E1) and 14.3% (E2). As error a has only 2 df, with CVs of 35% (E1) and 33% (E2), the test of manure rate has low power.

Table 4. ANOVA of the complete design (2 × 5 × 2): degrees of freedom, F values (probabilities) and error mean squares (MS)

Source of variation	df	Yield E1: F (p)	Yield E2: F (p)	pH-water E1: F (p)	pH-water E2: F (p)
Block	2	2.02 (0.331)	1.15 (0.464)	0.12 (0.892)	9.57 (0.095)
Manure rate (A)	1	4.02 (0.183)	64.63 (0.015)*	0.03 (0.880)	438.86 (0.002)**
Error a	2	MS = 486.3	MS = 334.8	MS = 0.1422	MS = 0.0035
Fertilizer rate (B)	4	44.75 (< 0.001)***	32.51 (< 0.001)***	0.63 (0.645)	6.42 (0.003)**
A × B	4	0.81 (0.537)	5.91 (0.004)**	0.56 (0.696)	1.54 (0.238)
Error b	16	MS = 63.3	MS = 59.8	MS = 0.0574	MS = 0.0831
Fertilizer type (C)	1	2.39 (0.138)	0.06 (0.802)	0.87 (0.361)	1.37 (0.256)
A × C	1	4.45 (0.048)*	0.14 (0.716)	5.08 (0.036)*	1.65 (0.213)
B × C	4	0.71 (0.595)	0.49 (0.743)	0.65 (0.631)	8.23 (< 0.001)***
A × B × C	4	1.86 (0.157)	0.90 (0.480)	2.44 (0.080)	8.08 (< 0.001)***
Error c	20	MS = 129.8	MS = 64.1	MS = 0.0552	MS = 0.0488
Total	59				
CV a / b / c (%)		35.4 / 12.8 / 18.3	32.7 / 13.8 / 14.3	6.6 / 4.2 / 4.1	1.1 / 5.4 / 4.2

Yield in t/ha (MS in $(t/ha)^2$). Each stratum is tested against its own error: A against error a, B and A × B against error b, C and its interactions against error c. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

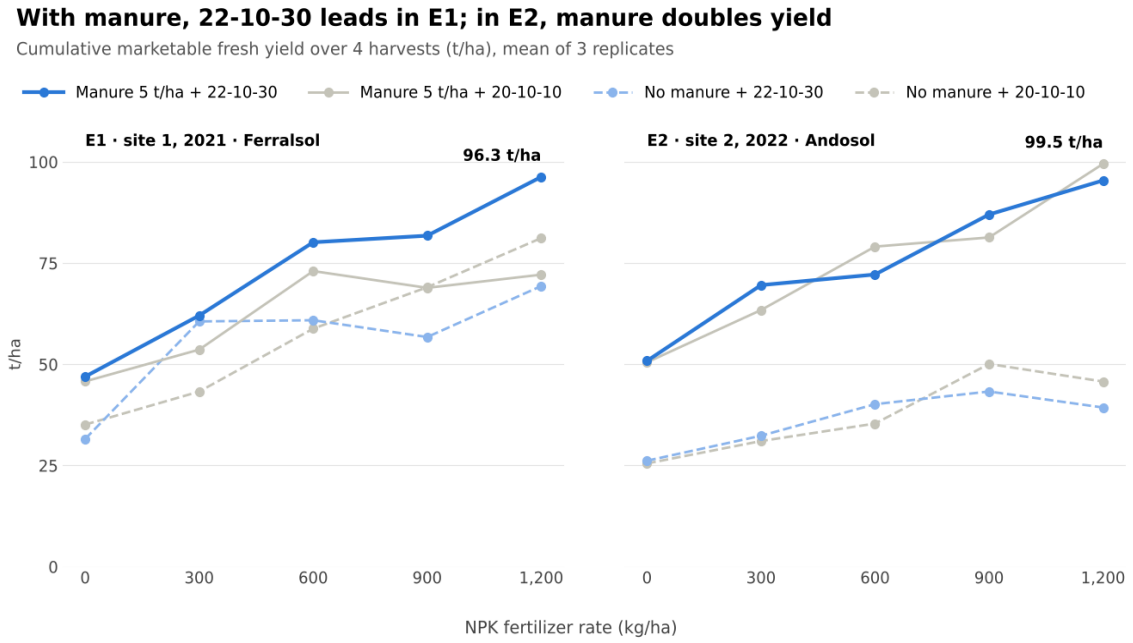
Table 5. ANOVA restricted to the fertilized rates (2 × 4 × 2; T1, T2, T11 and T12 excluded): degrees of freedom, F values (probabilities) and error mean squares (MS)

Source of variation	df	Yield E1: F (p)	Yield E2: F (p)	pH-water E1: F (p)	pH-water E2: F (p)
Block	2	2.20 (0.313)	0.88 (0.531)	0.31 (0.761)	4.41 (0.185)
Manure rate (A)	1	3.65 (0.196)	54.41 (0.018)*	0.13 (0.749)	84.76 (0.012)*
Error a	2	MS = 398.4	MS = 375.7	MS = 0.1256	MS = 0.0077
Fertilizer rate (B)	3	17.12 (< 0.001)***	14.72 (< 0.001)***	0.77 (0.534)	0.69 (0.578)
A × B	3	0.90 (0.472)	3.62 (0.046)*	0.56 (0.653)	0.19 (0.902)
Error b	12	MS = 72.7	MS = 70.4	MS = 0.0611	MS = 0.1089

Fertilizer type (C)	1	3.82 (0.068)	0.10 (0.756)	2.10 (0.166)	10.45 (0.005)**
A × C	1	5.48 (0.033)*	0.16 (0.694)	2.10 (0.166)	0.23 (0.638)
B × C	3	0.73 (0.550)	0.55 (0.656)	0.05 (0.985)	0.60 (0.626)
A × B × C	3	2.70 (0.080)	1.03 (0.405)	2.56 (0.091)	5.13 (0.011)*
Error c	16	MS = 112.4	MS = 73.9	MS = 0.0619	MS = 0.0581
Total	47				
CV a / b / c (%)		29.4 / 12.5 / 15.6	32.1 / 13.9 / 14.3	6.2 / 4.3 / 4.3	1.7 / 6.3 / 4.6

Analysis used to test fertilizer type (C) and its interactions. Same conventions as in Table 4.

Figure 1. Cumulative marketable fresh yield by fertilizer rate, manure rate and fertilizer type



Means of 3 replicates (data per EU: Boyomo Sanga thesis, Appendices 4 and 5). At rate 0, the two points with the same manure rate correspond to the pairs of identical treatments T1/T2 and T11/T12.

In E1, on the fertilized rates (300 to 1,200 kg/ha), the two fertilizers gave comparable yields without manure (63.1 t/ha for 20-10-10 and 61.9 t/ha for 22-10-30), but 22-10-30 clearly outperformed 20-10-10 with 5 t/ha of manure (80.1 vs 66.9 t/ha, i.e. +13.1 t/ha or +20%; 95% CI of the difference: 4.0 to 22.3 t/ha; Table 6). The highest yield (96.3 t/ha) was obtained with 5 t/ha of manure and 1,200 kg/ha of 22-10-30 (T20), 2.9 times that of the control (33.3 t/ha, mean of T1 and T2).

Table 6. Marketable fresh yield in E1: manure rate × fertilizer type interaction (rates 300 to 1,200 kg/ha)

Manure rate (A)	**20-10-10 (t/ha)**	**22-10-30 (t/ha)**	**Difference 22-10-30 − 20-10-10 (t/ha)**	**95% CI of the difference (t/ha)**
No manure	63.1	61.9	−1.2	−10.4 à 8.0
5 t/ha of manure	66.9	80.1	+13.1	4.0 à 22.3

Means of rates 300 to 1,200 kg/ha (12 EUs per mean). SED for comparing the two fertilizer types at the same manure rate: 4.33 t/ha (error c, 16 df); SED for comparing the two manure rates for the same fertilizer type: 6.52 t/ha.

In E2, the effect of manure dominated: 74.9 t/ha with 5 t/ha of manure vs 36.9 t/ha without manure (mean of the five fertilizer rates). With manure, yield increased steadily with fertilizer rate, from 50.7 t/ha without fertilizer to 97.5 t/ha at 1,200 kg/ha. Without manure, it rose only from 25.9 to 46.7 t/ha at 900 kg/ha, and the value obtained at 1,200 kg/ha (42.5 t/ha) does not differ significantly from that obtained at 900 kg/ha (Table 7). The two fertilizer types gave equivalent yields (56.2 t/ha for 20-10-10 and 55.6 t/ha for 22-10-30).

Table 7. Marketable fresh yield in E2 (t/ha): manure rate × fertilizer rate interaction

Manure rate (A)	**0 kg/ha**	**300 kg/ha**	**600 kg/ha**	**900 kg/ha**	**1,200 kg/ha**
No manure	25.9	31.7	37.8	46.7	42.5
5 t/ha of manure	50.7	66.5	75.6	84.2	97.5

Means of the two fertilizer types (6 EUs per mean). SED for comparing two fertilizer rates at the same manure rate: 4.46 t/ha (error b, 16 df); SED for comparing the two manure rates at the same fertilizer rate: 6.19 t/ha.

Soil pH

In E1, the A × C interaction on pH-water was significant in the complete design ($p = 0.036$): with 5 t/ha of manure, mean pH-water was 5.84 with 22-10-30 vs 5.65 with 20-10-10. This interaction is no longer significant when the analysis is restricted to the fertilized rates ($p = 0.166$; 5.84 vs 5.63), and no other effect is significant. Final pH-water remained between 5.4 and 5.9 for all treatments (initial pH 5.9), and no fertilized treatment deviates significantly from the initial pH (Table 8).

In E2, on an initially more acidic soil (pH-water 5.3), the analysis restricted to the fertilized rates shows a significant effect of manure rate (5.34 with manure vs 5.10 without; $p = 0.012$), of fertilizer type (5.33 with 22-10-30 vs 5.11 with 20-10-10; $p = 0.005$) and of the A × B × C interaction ($p = 0.011$), but not of fertilizer rate ($p = 0.578$). In the complete design, fertilizer rate ($p = 0.003$) and the B × C and A × B × C interactions ($p < 0.001$) are significant, but these effects are largely driven by the unfertilized plots, in particular T11 (6.53), whose pH exceeds by more than one unit that of T12 (5.47), although the treatment is identical. Mean pH-water thus goes from 5.67 without fertilizer to 5.31, 5.27, 5.15 and 5.16 from 300 to 1,200 kg/ha. By treatment (Table 8), the only significant declines relative to the initial pH concern T7 (900 kg/ha of 20-10-10 without manure: −0.57; 95% CI −0.71 to −0.42) and T10 (1,200 kg/ha of 22-10-30 without manure: −0.30; 95% CI −0.55 to −0.05). With 5 t/ha of manure and 22-10-30 (T14, T16, T18 and T20), final pH ranged from 5.17 to 5.70, with no significant difference from the initial pH; with manure and 20-10-10 (T13, T15, T17 and T19), it ranged from 4.97 to 5.37.

Table 8. Soil pH-water after the four harvests, by treatment, in both environments

Code	**A (t/ha)**	**B(kg/ha)**	**C**	**pH-water E1**	**Δ E1 [95% CI]**	**pH-water E2**	**Δ E2 [95% CI]**
T1	0	0	(20-10-10)	5.90 ± 0.15	0.00 [−0.66; +0.66]	5.37 ± 0.03	+0.07 [−0.08; +0.21]
T2	0	0	(22-10-30)	5.50 ± 0.00	−0.40 [−0.40; −0.40]	5.30 ± 0.06	0.00 [−0.25; +0.25]
T3	0	300	20-10-10	5.83 ± 0.24	−0.07 [−1.10; +0.97]	5.17 ± 0.03	−0.13 [−0.28; +0.01]
T4	0	300	22-10-30	5.73 ± 0.09	−0.17 [−0.55; +0.21]	5.27 ± 0.17	−0.03 [−0.75; +0.68]

T5	0	600	20-10-10	5.77 ± 0.23	−0.13 [−1.14; +0.87]	5.17 ± 0.19	−0.13 [−0.93; +0.67]
T6	0	600	22-10-30	5.93 ± 0.03	+0.03 [−0.11; +0.18]	5.20 ± 0.06	−0.10 [−0.35; +0.15]
T7	0	900	20-10-10	5.60 ± 0.12	−0.30 [−0.80; +0.20]	4.73 ± 0.03	−0.57 [−0.71; −0.42] *
T8	0	900	22-10-30	5.80 ± 0.06	−0.10 [−0.35; +0.15]	5.33 ± 0.15	+0.03 [−0.59; +0.66]
T9	0	1,200	20-10-10	5.90 ± 0.06	0.00 [−0.25; +0.25]	4.97 ± 0.18	−0.33 [−1.09; +0.43]
T10	0	1,200	22-10-30	5.63 ± 0.09	−0.27 [−0.65; +0.11]	5.00 ± 0.06	−0.30 [−0.55; −0.05] *
T11	5	0	(20-10-10)	5.70 ± 0.06	−0.20 [−0.45; +0.05]	6.53 ± 0.03	+1.23 [+1.09; +1.38] *
T12	5	0	(22-10-30)	5.83 ± 0.15	−0.07 [−0.69; +0.56]	5.47 ± 0.07	+0.17 [−0.12; +0.45]
T13	5	300	20-10-10	5.50 ± 0.15	−0.40 [−1.06; +0.26]	5.30 ± 0.17	0.00 [−0.75; +0.75]
T14	5	300	22-10-30	5.90 ± 0.06	0.00 [−0.25; +0.25]	5.50 ± 0.10	+0.20 [−0.23; +0.63]
T15	5	600	20-10-10	5.83 ± 0.03	−0.07 [−0.21; +0.08]	5.20 ± 0.06	−0.10 [−0.35; +0.15]
T16	5	600	22-10-30	5.83 ± 0.09	−0.07 [−0.45; +0.31]	5.50 ± 0.06	+0.20 [−0.05; +0.45]
T17	5	900	20-10-10	5.80 ± 0.35	−0.10 [−1.61; +1.41]	5.37 ± 0.18	+0.07 [−0.69; +0.83]
T18	5	900	22-10-30	5.80 ± 0.06	−0.10 [−0.35; +0.15]	5.17 ± 0.30	−0.13 [−1.41; +1.14]
T19	5	1,200	20-10-10	5.40 ± 0.15	−0.50 [−1.16; +0.16]	4.97 ± 0.12	−0.33 [−0.85; +0.18]
T20	5	1,200	22-10-30	5.83 ± 0.09	−0.07 [−0.45; +0.31]	5.70 ± 0.29	+0.40 [−0.84; +1.64]

Mean ± standard error (n = 3). Δ: deviation from the initial pH (E1: 5.9; E2: 5.3) and 95% CI (t with 2 df); *: 95% CI excluding 0. In brackets: type assigned without fertilizer application (identical pairs T1/T2 and T11/T12). SED for comparing the two fertilizer types at the same manure and fertilizer rates (complete design): 0.19 (E1) and 0.18 (E2).

Economic profitability

The VCRs recalculated with the price of the prepared 22-10-30 (735 FCFA/kg) are given in Table 9. The values of the previous version, calculated with the price of a commercial 22-10-30 (685 FCFA/kg), overestimated the VCR of the 22-10-30 treatments by 0.05 to 0.30 points (e.g. 5.68 instead of 5.58 for T16 in E1); the VCRs of the 20-10-10 treatments are unchanged. In E1, all fertilized treatments were profitable (VCR of 3.13 to 9.90). The highest VCR was that of 300 kg/ha of 22-10-30 without manure (T4; 9.90), but the highest net benefit was obtained with 5 t/ha of manure and 1,200 kg/ha of 22-10-30 (T20; 10.29 million FCFA/ha). In E2, VCRs ranged from 2.52 (T10) to 6.89 (T19), and the highest net benefit was that of T19 (5 t/ha of manure and 1,200 kg/ha of 20-10-10; 12.60 million FCFA/ha).

Table 9. Economic profitability of the treatments in both environments, recalculated with the price of the prepared 22-10-30 (735 FCFA/kg)

Treatment (A; B; C)	**E1 (site 1, 2021)**				**E2 (site 2, 2022)**			
	AY (t/ha)	**TC_2 (10^3 FCFA/ha)**	**VCR**	**NB (10^6 FCFA/ha)**	**AY (t/ha)**	**TC_2 (10^3 FCFA/ha)**	**VCR**	**NB (10^6 FCFA/ha)**
T3 · 0 t; 300 kg; 20-10-10	9.9	287	6.91	1.70	5.2	235	4.42	0.80

T4 · 0 t; 300 kg; 22-10-30	27.3	550	9.90	4.90	6.5	321	4.05	0.98
T5 · 0 t; 600 kg; 20-10-10	25.5	611	8.33	4.48	9.5	435	4.38	1.47
T6 · 0 t; 600 kg; 22-10-30	27.6	778	7.09	4.73	14.3	631	4.53	2.23
T7 · 0 t; 900 kg; 20-10-10	35.7	877	8.14	6.26	24.2	750	6.46	4.10
T8 · 0 t; 900 kg; 22-10-30	23.4	956	4.90	3.73	17.4	890	3.92	2.60
T9 · 0 t; 1,200 kg; 20-10-10	47.9	1,163	8.23	8.41	19.9	854	4.66	3.13
T10 · 0 t; 1,200 kg; 22-10-30	36.0	1,319	5.46	5.88	13.5	1,070	2.52	1.63
T11/T12 · 5 t; 0 kg	13.0	833	3.13	1.77	24.8	963	5.16	4.00
T13 · 5 t; 300 kg; 20-10-10	20.3	1,090	3.72	2.97	37.6	1,281	5.86	6.23
T14 · 5 t; 300 kg; 22-10-30	28.7	1,255	4.58	4.49	43.7	1,421	6.15	7.32
T15 · 5 t; 600 kg; 20-10-10	39.7	1,457	5.45	6.48	53.2	1,607	6.63	9.04
T16 · 5 t; 600 kg; 22-10-30	46.8	1,679	5.58	7.68	46.3	1,674	5.54	7.59
T17 · 5 t; 900 kg; 20-10-10	35.6	1,564	4.55	5.55	55.5	1,784	6.22	9.31
T18 · 5 t; 900 kg; 22-10-30	48.4	1,921	5.04	7.77	61.2	2,062	5.93	10.17
T19 · 5 t; 1,200 kg; 20-10-10	38.8	1,752	4.43	6.01	73.7	2,138	6.89	12.60
T20 · 5 t; 1,200 kg; 22-10-30	63.0	2,306	5.46	10.29	69.6	2,379	5.85	11.54

AY: additional yield over the control (mean of T1 and T2: 33.3 t/ha in E1 and 25.9 t/ha in E2); TC_2: total cost including interest; VCR = VAY / TC_2; NB = VAY − TC_2. Prices: nightshade 200 FCFA/kg; 20-10-10 500 FCFA/kg; prepared 22-10-30 735 FCFA/kg; manure 125 FCFA/kg (Table 20 of the thesis). The "manure only" treatment is the mean of T11 and T12.

Marginal analysis (CIMMYT, 1988) eliminates many dominated treatments. In E1, the non-dominated treatments are T3, T4, T7, T9 and T20; moving from T9 (1,200 kg/ha of 20-10-10 without manure) to T20 still returns 1.65 FCFA per additional FCFA invested (MRR of 165%). In E2, the sequence of non-dominated treatments ends with T19, with an MRR above 100% at each step. On net benefit alone, 1,200 kg/ha combined with manure would therefore be recommended in both environments; Section 4.4 explains why another treatment was retained.

Table 10. Sensitivity of the VCR to prices for six representative treatments, number of profitable treatments and economic optimum

Scenario	Env.	T4	T5	T15	T16	T19	T20	VCR ≥ 2	Optimum
Baseline (200 FCFA/kg; Table 20 prices)	E1	9.90	8.33	5.45	5.58	4.43	5.46	17/17	T20
	E2	4.05	4.38	6.63	5.54	6.89	5.85	17/17	T19
Nightshade price −25% (150 FCFA/kg)	E1	7.43	6.25	4.09	4.18	3.32	4.10	17/17	T9
	E2	3.04	3.28	4.97	4.15	5.17	4.39	16/17	T19
Nightshade price −50% (100 FCFA/kg)	E1	4.95	4.17	2.72	2.79	2.22	2.73	15/17	T9
	E2	2.03	2.19	3.31	2.77	3.45	2.92	15/17	T19
Mineral fertilizers +25%	E1	9.00	7.42	5.18	5.23	4.08	4.98	17/17	T20
	E2	3.46	3.73	6.33	5.19	6.44	5.35	17/17	T19
Mineral fertilizers and manure +50%	E1	8.24	6.69	4.13	4.23	3.28	4.11	17/17	T9
	E2	3.01	3.25	5.14	4.19	5.35	4.44	16/17	T19
22-10-30 at 919 FCFA/kg (+25%)	E1	9.00	8.33	5.45	5.23	4.43	4.98	17/17	T20
	E2	3.46	4.38	6.63	5.19	6.89	5.35	17/17	T19
Nightshade −50% and inputs +50%	E1	4.12	3.34	2.07	2.11	1.64	2.06	10/17	T9
	E2	1.51	1.62	2.57	2.10	2.68	2.22	9/17	T19

T4: 300 kg/ha of 22-10-30 without manure; T5: 600 kg/ha of 20-10-10 without manure; T15 and T16: 600 kg/ha of 20-10-10 or 22-10-30 with 5 t/ha of manure; T19 and T20: 1,200 kg/ha of 20-10-10 or 22-10-30 with manure. VCR ≥ 2: number of fertilized treatments (out of 17) reaching the threshold. Optimum: treatment with the highest net benefit and an MRR ≥ 100%.

The sensitivity analysis (Table 10) shows that the conclusions withstand price changes taken individually: at least 15 of the 17 fertilized treatments keep a VCR ≥ 2 in each scenario. Only the combined scenario (nightshade price −50% and inputs +50%) sharply reduces the number of profitable treatments (10 in E1 and 9 in E2); in this scenario, only T7, T15, T16 and T20 remain above the threshold of 2 in both environments. The break-even price of nightshade (VCR = 2) is 72 FCFA/kg for T16 in both environments, against 40 and 99 FCFA/kg for T4, 73 and 68 FCFA/kg for T20, and 90 and 58 FCFA/kg for T19 (E1 and E2), for a market price of 200 FCFA/kg.

DISCUSSION

The advantage of 22-10-30 depends on manure and on the environment

In E1, the advantage of 22-10-30 over 20-10-10 appeared only in the presence of manure: +13.1 t/ha (95% CI: 4.0 to 22.3 t/ha) on the fertilized rates, against no difference without manure. In E2, yield did not differ between the two fertilizers. The nutrient input balance partly explains this advantage. At 600 kg/ha, 20-10-10 covers nitrogen removal (120 vs 121 kg/ha) but only one third of potassium removal (60 vs 177 kg/ha of K_2O); 22-10-30 covers both (132 kg/ha of N and 180 kg/ha of K_2O) (Eone, 2018). The potassium shortfall of 20-10-10 must therefore be met by soil reserves or by manure.

That the advantage of 22-10-30 appears only with manure suggests that potassium is not the only limiting factor. Without organic input, phosphorus nutrition and soil biological activity could limit the use of the extra potassium: both fertilizers supply only 60 kg/ha of P_2O_5 at 600 kg/ha, against 143 kg/ha removed, and manure, rich in phosphorus (5,700 to 6,900 mg/kg total P), offsets part of this deficit. This interpretation remains a hypothesis, as plant nutrient status was not measured.

Two distinct environments: the response to fertilizers is not simply a soil effect

In E2, manure doubled yields and fertilizer type did not change yield. It is tempting to attribute this contrast to the poverty of the Andosol (base saturation of 29%, 5 mg/kg of Bray II P), on which organic matter improves phosphorus availability, complexes aluminium and retains cations (Hue et al., 1986). But E1 and E2 differ in many other factors that cannot be separated from soil in this design: site, year, growing season (transplanting in February vs October), water regime (16.6% vs 96% of water supplied by irrigation), climatic land suitability (S2 vs S3) and manure composition, which varied greatly between batches (Table 1): at 5 t/ha, manure supplied about 71 kg/ha of nitrogen in E1 against 172 kg/ha in E2, based on the analysed contents. Each environment must therefore be interpreted on its own, and the differences between E1 and E2 cannot be attributed to soil type alone.

Without manure, yield in E2 levelled off at about 47 t/ha (900 kg/ha of 20-10-10); the lower value obtained at 1,200 kg/ha (42.5 t/ha) does not differ significantly from that obtained at 900 kg/ha. The variability of manure also shows that a recommendation expressed in tonnes per hectare does not guarantee a constant nutrient supply. Simultaneous trials on several sites, with a homogeneous manure batch, would be needed to isolate the soil effect. These results remain consistent with the principle of integrated soil fertility management (Bationo et al., 2004; Vanlauwe et al., 2010).

The yields obtained are in the same range as those reported in the region under organo-mineral fertilization: 63 t/ha with 45 t/ha of manure and 400 kg/ha of 10-10-20 (Neleyo, 2000), 57.3 t/ha with 10 t/ha of manure and 120 kg/ha of nitrogen (Ondo, 2004), and 61 t/ha with 5 t/ha of manure and 600 kg/ha of 20-10-10 (Eone, 2018). A moderate rate of manure, combined with a suitable fertilizer, is thus enough to achieve high yields.

Effect of fertilization on soil pH

In E2, the final pH-water of the fertilized plots was higher with 22-10-30 than with 20-10-10 (5.33 vs 5.11; $p = 0.005$), and higher with manure than without (5.34 vs 5.10; $p = 0.012$). The only significant declines relative to the initial pH concern treatments without manure (T7: −0.57 units; T10: −0.30 units). These results are consistent with the acidifying effect of ammonium and urea fertilizers, whose nitrification releases H^+ ions (Rabeharisoa, 2004), and with the pH declines observed under exclusive mineral fertilization (Bado, 2002; Mills and Fey, 2003). However, fertilizer rate had no significant effect on the pH of the fertilized plots ($p = 0.578$). The lowest values (4.7 to 5.0) remain well below the optimum for black nightshade (6.0 to 6.5; Oko, 2002). In E1, no fertilized treatment significantly changed the pH, which remained between 5.4 and 5.9.

The buffering effect of manure is explained by its neutral to slightly alkaline pH (7.0 to 7.7), the bases it supplies and the ability of its organic matter to complex aluminium (Whalen et al., 2000). The lower acidifying effect of 22-10-30 may stem from its higher potassium content, which helps saturate the exchange complex, and from a

lower proportion of ammonium nitrogen per unit of K_2O; this hypothesis remains to be tested. Two limitations call for caution. First, the pH values are based on three replicates, and the 95% CIs are wide. Second, treatments T11 and T12, which are identical (5 t/ha of manure, no fertilizer), gave very different pH values in E2 (6.53 vs 5.47), reflecting strong heterogeneity between EUs, probably related to the distribution of manure. Moderate liming combined with organo-mineral fertilization would be one way to keep pH in the optimal range (Bado et al., 1997).

Choice of the recommended rate, profitability and sustainability

The highest VCR was obtained in E1 with 300 kg/ha of 22-10-30 without manure (T4; 9.90). This treatment was nevertheless not retained, for three reasons. First, a high ratio on a small investment does not necessarily provide the largest gain: the net benefit of T4 (4.90 million FCFA/ha) is lower than that of T16 (7.68 million FCFA/ha). Second, it is not stable: in E2, its VCR falls to 4.05 and its net benefit to 0.98 million FCFA/ha, and it falls below the threshold of 2 in the least favourable price scenario (1.51). Third, treatments without manure are the most acidifying in E2. The other treatments without manure with a high VCR in E1 (T5, T7 and T9) all have, in E2, a much lower net benefit (1.5 to 4.1 million FCFA/ha) than the treatments with manure, and T7 caused the largest pH decline in the trial.

Marginal analysis identifies, in both environments, 1,200 kg/ha combined with manure as the most profitable rate: T20 in E1 (net benefit of 10.29 million FCFA/ha; MRR of 165% relative to T9) and T19 in E2 (12.60 million FCFA/ha). The choice of 600 kg/ha of 22-10-30 with 5 t/ha of manure (T16) is therefore a trade-off, not profit maximization. This trade-off rests on four arguments. (i) Robustness: T16 is one of the four treatments (with T7, T15 and T20) whose VCR remains ≥ 2 in both environments and in all price scenarios, with a break-even nightshade price of 72 FCFA/kg in both environments, against 200 FCFA/kg on the market. (ii) Stability: its net benefit is almost identical in E1 and E2 (7.68 and 7.59 million FCFA/ha), whereas that of T19 ranges from 6.01 to 12.60 million. (iii) Nitrogen balance: 600 kg/ha of 22-10-30 supplies 132 kg/ha of nitrogen, close to the 121 kg/ha removed, whereas 1,200 kg/ha supplies 240 to 264 kg/ha, twice the removal, with a risk of nitrate accumulation in leaves, already observed in black nightshade (Engonga, 2007), and of leaching in these highly porous soils. (iv) pH: T16 did not lower pH in E1 (5.83; initial pH 5.9) or in E2 (5.50; initial pH 5.3), whereas T19 lowered it to 5.40 and 4.97. The cost of this choice is a loss of income relative to the economic optimum of 2.60 million FCFA/ha in E1 and 5.00 million FCFA/ha in E2.

Finally, T16 and T15 (600 kg/ha of 20-10-10 with manure) are economically equivalent on average across the two environments (mean net benefit of 7.64 vs 7.76 million FCFA/ha): 22-10-30 is more profitable in E1 and 20-10-10 in E2. The use of 22-10-30 is justified mainly by the potassium balance, which 20-10-10 leaves in deficit by about 117 kg/ha of K_2O per cycle at 600 kg/ha, and by the higher pH observed in E2 (5.50 vs 5.20 for T15). The VCR does not account for these effects on soil fertility; multi-year monitoring of the potassium balance, pH and leaf nitrates would make it possible to quantify them.

CONCLUSION

In this trial conducted in two distinct environments, 22-10-30, formulated from black nightshade nutrient removal and prepared from 20-10-10, outyielded 20-10-10 only in the presence of poultry manure in E1 (Ferralsol, 2021): +13.1 t/ha (+20%) on the fertilized rates, with a maximum of 96.3 t/ha. In E2 (Andosol, 2022), manure doubled yields and fertilizer type did not change yield; 22-10-30 nevertheless left a higher pH than 20-10-10. These differences between environments cannot be attributed to soil type alone, as the season, water regime and manure quality also changed. All fertilized treatments were profitable (VCR of 2.5 to 9.9 with the recalculated price of 22-10-30). The economic optimum corresponds to 1,200 kg/ha of fertilizer with manure, but this rate supplies twice the nitrogen removed. The combination of 5 t/ha of manure and 600 kg/ha of 22-10-30 is recommended as a trade-off: it is profitable in all price scenarios tested and in both environments, with a nitrogen supply close to crop removal and no measured decline in pH. Simultaneous trials on several soils, with a homogeneous manure batch and monitoring of leaf nitrates and the potassium balance, are needed to confirm these results.

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