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Towards Management of South Kivu Ferralsols by the Contribution of Different Types of Fertilizers: Their Influence on the Biofortified Climbing Bean Behaviour

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Abstract For many tropical and subtropical countries, poor soil fertility management is still a major problem in agricultural production and requires sustained attention. This study was carried out to evaluate the effect of the combination of fertilizer types on the improvement of ferralsol properties and on biofortified climbing bean yield in South Kivu. The experimental field was conducted by using a CRB plot with three replications. Ten treatments were followed consisted of a control, mineral fertilizer NPK (150 kgha^{-1}), farmyard manure (30 tha^{-1}), liming (1.3 tha^{-1}), fresh biomass of *Tithonia diversifolia* (30 tha^{-1}), and their combinations. The results obtained show significant differences between the treatments and their ability to improve the chemical properties (acidity, OM, N, and K) of the ferralsol during the two cropping seasons. This improvement has led to improvements significantly in the growth, yield, and profitability of climbing beans. The combination of farm manure and NPK (2.6 tha^{-1}); liming-NPK and straw biomass of *Tithonia sp.* presented the same yield performance. With a profit margin of 900 and 850 USDha-1, *Tithonia sp.* could replace expensive mineral fertilizers. This study shows that liming coupled with low rates of fertilizer or *Tithonia* sp. on ferralsol in eastern RD Congo conditions and have the potential for improving the availability of soil nutrients and providing the quantities required nutrients needed for growing biofortified climbing beans and thus reduce malnutrition in the region subsequently fight against Fe and Zn micronutrient deficiency.

Keywords: *biofortification, ferralsols, fertilizers, bean yield, and South Kivu*

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1. Introduction

For many tropical and subtropical countries, poor soil fertility management is still a major problem in agricultural production and requires sustained attention. This problem is related to the insufficiency of the mineral elements with a weak contribution of input, soil acidity, and accentuated by the erosion. This results in biological, chemical, and physical soil degradation with decreasing soil organic matter content and declining fertility [1,2,3].

An estimate of the state of nutrient depletion has been made for sub-Saharan countries and losses have been estimated at an average of 24 kgh^{-1}yr^{-1} of nutrients (10 kg N, 4 kg P_2O_5, and 10 kg of K_2O) and [4] 48 kg ha^{-1}yr^{-1}, a loss equivalent to 100 kgha^{-1}yr^{-1} of 17-17-17 NPK fertilizer. One of the causes is that farmers do not have access to fertilizer in a timely manner and when there is access, the price is 3 to 10 times higher than elsewhere in the world. To this is added the superposition of tax systems and weakness of transport infrastructure. As a result, a very small amount of fertilizer is used [5,6].

The soil fertilizer input according to the reasoned fertilization model (GIFS) improves the fertility of the soil by achieving the practical objectives of productivity management, profitability, sustainability of crop systems [7,8]. Besides, the organic or mineral forms cannot fulfil these two needs without each other. Indeed, the combination of organic matter and fertilizer generated 4 tha^{-1} yields versus 2 tha^{-1} for manure alone in the experiment conducted by [9]. Improved yield of beans on pickled soil by fertilizing with mineral and organic fertilizers; the yield ranged from 2.05 $t.ha^{-1}$ to 2.85 tha^{-1} while the control only showed 1.5 $t.ha^{-1}$ [10,11].

Given all this, the need to improve crop yields and productivity on existing farmland is becoming a primary goal. Soil fertility is therefore a complex notion that will depend on the crop in place, the climate, and the technical capacity of the producer. As a result, the improvement of cultural techniques (including the supply of organic and chemical fertilizers), the selection of the most productive varieties.

Research shows that it is possible to maintain agricultural production at much higher levels and more rational use of fertilizers of all kinds. For a small producer with a limited income, fertilizers are expensive; however, if each franc used for fertilizer purchases earns five francs [12,13], farmers should look for the best way to make their money profitable through formulas and combinations of organic and mineral fertilizers. To maximize harvests; farmers sometimes ask for a credit to increase their capital.

The case of DR Congo in general and South Kivu, in particular, does not remain untouched by this problem. Low soil fertility is one of the factors limiting yield in highland bean-producing areas; this is the case is more observed in the East. The main problems relating to soil fertility have been found to include erosion, non-use of fertilizers, acidity and ferric and aluminium toxicity accentuated by the poverty of the source rock and poor farming techniques [14].

Beyond these constraints mentioned above, production must increase, but the methods must be economically viable and acceptable [15].

In the highlands such as Kivu in general and Walungu in particular, maintaining and improving soil fertility will depend on the use of mineral fertilizers, lime, green manure organic, cover crops, the use of agroforestry, and therefore good integrated nutrient management to increase crop yields.

It has been shown that the availability of P can be increased when the acidic soils are limed, resulting in higher yields of beans. also demonstrated that in twining beans, the average yield of 632 kg/ha can increase to 1250 kg/ha, 1186 kg/ha, and 1365 kg/ha, respectively, when Tithonia green biomass alone is applied. DAP and Tithonia-DAP. Recent field trials have shown that a nutrient application (NPK) adapted to soil characteristics and plant needs have resulted in a 50% increase in soil productivity [16].

Experiments conducted in Rwanda show that the OM (cow dung) added to the acid ferralsols at a rate of 30 tha^{-1} on bean crop allowed to reduce the level of the Al^{3+} exchangeable from 3.77 to 2.44 $Cmolkg^{-1}$, and Fe^{3+} from 4.0 to 2.7 $Cmolkg^{-1}$; while the massive amount of OM added (compost) elevated soil pH from 4.4 to 4.9 by a year.

The main constraint remains the availability in terms of OM as cattle and goat numbers have been declining steadily for decades. It will therefore be necessary to think of other fertilization alternatives on these poor soils and subsequently to take into account the purchasing power of the farmers in the area, especially based on the factors to practice technologies that are economically demanding.

This work aims to contribute to the improvement of bean production in the province of South Kivu by improving soil properties using different types of fertilizers. It consisted in evaluating the contribution effects of three types of fertilizers on the improvement of the properties of Kaziba's degraded ferralsols and then, evaluate the behavior of climbing bean in the application of these different types of fertilizers tested, identify the type of fertilizer that significantly increases the efficiency and profitability of beans.

2. Materials and Methods

2.1. Site Location and Description

The present study was carried out in the Chihumba village in Kaziba in the territory of Walungu, province of South Kivu eastern of RD Congo. The experimental site was located at 02°48'44.8"S; 028°48 '11.5"E and 1998 m of elevation. The relief in the middle is heavily hilly and consists of high mountains and hills interspersed with swampy plains.

Kaziba is a kingdom from Walungu territory which is general in a tropical humid climate. It is a *Cwb* type according to the Koppen classification (Figure 1b). The average annual temperature and rainfall are around 18.1 °C and 1681mm. The peak of the temperatures was observed in September (18.7°C) whereas for the precipitations March (213 mm) and December (211 mm) are the rainiest of months.

2.2. Soil in Walungu Territory

Soils of South Kivu and more particularly in the Walungu territories belong most often to the order of Ferralsols (Oxisols or ultisols, in soil taxonomy that [17,18] describes as soils knowing the phenomenon of Al^{3+} and Fe^{3+} toxicity, and then have a limitation in phosphorus.

Ferralsols are soils characteristic of equatorial regions where it rains abundantly, the parent rock being rich in ultimate alteration rock, a basic bedrock. With pH sometimes slightly acidic, a significant proportion of kaolinitic clay (type 1: 1). A very low cation exchange capacity (CEC) and rich in Fe and Al oxide giving it its reddish color (Fig. 2). Old metamorphic and sedimentary rocks with low natural fertility are predominate. They are generally characterized by the presence of a structural B-horizon with a well-developed polyhedral structure, in which at least 50% of the surface of the aggregates is covered by clay layers, whereas the characteristics of their A_1 horizon are determined by altitude [19].

[20] Showed that acid soil infertility encompasses several soil chemical and biological functions: Al toxicity, N, P, Ca, and Mg deficiencies and sometimes very low populations of symbiotic nitrogen-fixing bacteria and mycorrhizae. The plant material used for the experimental trial was the G59/1-2 climbing bean variety. This variety has been popularized by HarvestPlus since 2015. The seed used was from the INERA/Mulungu faba program.

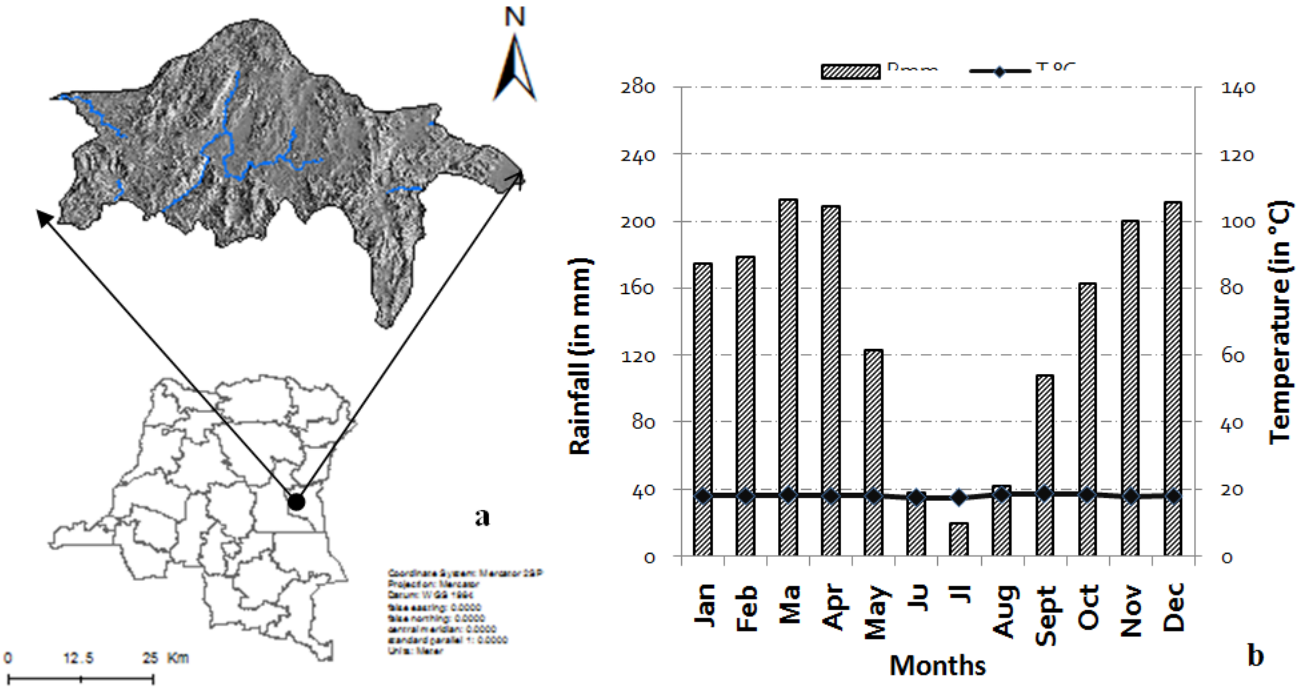

Figure 1. Study area in Walungu territory (a) and rainfall (b) in the trial period

Table 1. Chemical analysis of fertilizers used and soil of the site

Soil caracteristics	Parameters								
Analyse	**pH (H_2O)**	**$P_{(ass)}$ in ppm**	**N $g.kg^{-1}$**	**K $g.kg^{-1}$**	**% C**	**C/N**	**%MO**	**Ca $g.kg^{-1}$**	**Mg $g.kg^{-1}$**
Soil	5.58±0.2	3.15	0.291	1.62	1.14	3.79	2.78	4.21	1.41
NPK	-	0.42	0.17	0.17	-	-	-	-	-
OM	8.04	59.6	0.98	4.57	22.4	13.75	38	1,7	0,21
Tithonia leaves	6.82	9	3.2	4.82	34.8	10.5		2.8	0.6

Two types of the amendment were used: organic manure and mineral fertilizer. Organic manure was also of two types, farm manure and the fresh biomass of *Tithonia diversifolia*. The chemical analysis of the equipment used is shown in Table 1.

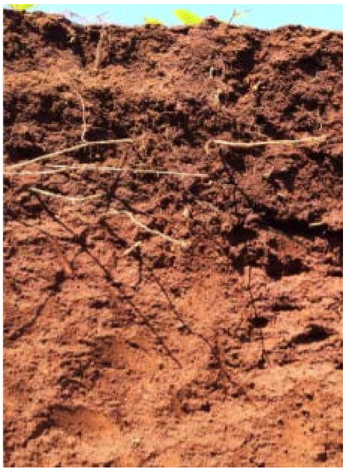

Figure 2. Soil in Walungu territory

The data in the table show that pH-$_{H2O}$ of Kaziba ferralsols is 5.58±0.2; the pH-value of the organic fertilizer is basic which would contribute to the improvement of the ferralsols acidity. The carbon content is not an acceptable level (1.14%); it is above the critical threshold è 6.2 recommended by [22]. The amount of P is very low than the optimum, which is estimated at 15 ppm. The nitrogen content (0.291%) is also below the recommended 0.3% threshold in bean cultivation. The amount of NPK 17-17-17 applied was 100 $kgha^{-1}$. A quantity evaluated at 50 kg.ha-1 of P (TSP) was added before harvesting.

2.3. Method and Observed Parameters

The method used was based on field experimentation. The study was conducted according to a Completely Randomized Block Design (CRBD) with 3 replications for each treatment. In each block 10 treatments were applied: the ten packets or types of fertilizers tested. Treatments were randomized within each block. The plot area was 725 m² or 50 mx14.5 m. Manure and fresh biomass were applied at a rate of 30 tha^{-1} (48 kg per plot and 1 kg per seeding hole). The lime was applied at a rate of 1.3 tha^{-1} according to the formula recommended by [23,24]. The other treatments consisted of the combination of these three types.

Soil samples were collected before sowing and after three months of harvest. Soil collection was carried out in each plot, tagged, and sent to the soil laboratory of the Université Evangélique en Afrique (UEA/Bukavu) where the analyses were carried out.

The parameters observed on the soil were: soil acidity evaluated by the pH, it was measured by electrode pH-meter, organic matter (OM) determined from the total organic carbon according to the method of Walkley and Black; then, the carbon content was multiplied by the factor 1,724. Total nitrogen (N total): it was determined by the Kjeldahl method. Phosphorus available (Pass) was determined according to the Olsen method by spectrophotometry with molybdenum blue.

The rate of emergence the number of seeds emerged out of the total number of seeds sown at all multiply by one hundred. The height of the plants at flowering (45 days) was taken using a well-graduated ruler measure; eight plants per plot were chosen at random. The number of pods per plant, number of seeds per pod, and one hundred randomly picked seeds were weighed using a precision scale to determine one hundred seed weight for each plot. The weight of all seeds was reported per hectare by the rule of three simple to found the plot yield. Aerial biomass by measuring the weight of the plants in each plot, this measurement was made using the precision balance. Harvest index was calculated for each of the treatments using the following formula proposed by [25] and expressed in%.

For the economic analysis of the treatments, profitability was used for the calculation of the profit. The following parameters were observed: activity costs, local market input costs, the cost of applying these different inputs used, total costs, yield in $kgha^{-1}$, the price of 1 kg of bean in the market, the total productivity, the profit obtained. The cost of chemical fertilizers was the one observed in the Kaziba local market ($ 158 for 100 kg of NPK), $ 2.5 for 100 kg of cow dung, $ 33.3 for 100 kg of lime, and 0.4 $ for for for picking *Tithonia*. The average price of a ton of beans in the Kaziba market is around $ 600. The benefit of the different treatments was obtained by subtracting total productivity and total cost.

2.4. Statistical Analysis of the Data

R 2.3.3, Statistix 8.0, and MS Excel 2010 software was used for coding and analyzing the results. Measurement data were subjected to analysis of variance to reveal the differences between treatments. The Tukey HSD test of honestly significant differences was used for comparing the averages at 5% probability.

Table 2. Soil Analysis before Seeding and One Month After Harvesting Field Beans

Treatments	pH (H_2O)	P_{ass} (in ppm)	% Nitrogen	% Carbon	C/N
Control	5.91 ± 0.61^b	31.42 ± 0.76^f	0.30 ± 0.02^c	2.31 ± 0.2^c	7.86 ± 1.77^c
0.150 tha⁻¹ NPK	5.98 ± 0.54^b	31.79 ± 1.89^f	0.34 ± 0.03^c	2.55 ± 0.52^c	7.74 ±0.92c
30 tha⁻¹ cow dung	7.01 ± 0.42^a	49.1 ± 0.42^d	0.38 ± 0.03^b	2.65 ± 0.36^b	6.7 ± 1.56^c
1.3 tha⁻¹ lime	7.22 ± 0.28^a	39.8 ± 0.58^e	0.36 ± 0.02^c	2.91 ± 0.27^b	8.92 ± 1.25^b
30 tha⁻¹ Tithonia spp.	7.14 ± 0.3^a	61.7 ± 2.08^c	0.38 ± 0.03^b	3.1 ± 0.49^a	8.5 ± 0.49^b
Cow dung and lime	7.21 ± 0.17^a	71.1 ± 3.9^b	0.43 ± 0.08^a	3.76 ± 0.51^a	8.7 ± 0.93^b
Tithonia spp. and 0.150 tha⁻¹ NPK	7.05 ± 0.15^a	65.6 ± 4.1^{bc}	0.43 ± 0.03^a	3.3 ± 0.45^a	8.26 ± 0.25^b
Lime and 0.150 tha⁻¹ NPK	7.18 ± 0.32^a	38.8 ± 1.48^e	0.35 ± 0.0^c	2.95 ± 0.04^b	9.94 ± 0.26^a
Cow dung and 0.150 tha⁻¹ NPK	7.28 ± 0.28^a	91.42 ± 0.92^a	0.44 ± 0.03^a	2.8 ± 0.36^b	6.5 ± 0.23^c
Cow dung and Tithonia spp.	7.29 ± 0.31^a	62.5 ± 1.4^c	0.41 ± 0.02^{ab}	3.66 ± 0.39^a	9.48 ± 1.25^a
Means	6.96	54.32	0.38	2.92	8.39
P-value	*0.0001*	*0.0001*	*0.0031*	*0.014*	*0.0022*
Tukey HSD	0.7451	6.4714	0.1032	1.16	2.96
CV%	3.66	4.07	9.30	8.44	8.17

Legend: pH: hydrogen potential. C/N: carbon-nitrogen ratio. The values of a column with different letters are significantly different at the probability of the 5% Tukey HSD test.

3. Results and Discussion

3.1. Variation in Soil Properties after a Season of Production by Using Different Types of Fertilizers

Table 2 above shows that the pH, the P_{ass}, N, C, and the C/N ratio were significantly influenced (p ˂ *0.001*) by the application of these treatments. Some properties of ferralsol were positively improved. The highest pH was observed on plots treated with lime, dung combine with Tithonia, and combinations with an average of 7.21 while the control plots had the lowest values (5.91). The available phosphorus was raised on the plots treated with the association dung and mineral N-P-K fertilizer with an average of 91.42ppm whereas the control plots and NPK applied plot presented the lowest values. The percentage of Nitrogen was high on plots treated with the dung-NPK fertilizer association, *Tithonia* and NPK, and dung and lime with an average of 0.44%N while the control plots, the 150 $kgha^{-1}$ NPK (0.34%) and lime only had the lowest percentages with an average of 0.30 to 0.36%. On the other hand, the percentage of carbon was high on the plots treated with *Tithonia*, lime, dung, and their combination with an average of 2.92% whereas the control and NPK plots presented the lowest percentages with an average of 2.31%.

3.2. Effects of Fertilizer Types on Growth and Yield of Biofortified Climbing Bean Grown on ferralsol

Table 3 shows that there was no significant effect (p = *0.8971*) of these treatments on the rate of seed emergence. On the other hand, at flowering, the height of the plants varied very significantly (p = *0.001*) according to the treatments. The highest average was observed on plots treated with lime and cow dung (243.39 cm) while the control plots had the lowest value (97.81 cm). The above-ground biomass, the number of pods per plant, the number of seeds per pod, the weight of one hundred seeds, and the harvest index were influenced very significantly by treatments ($p \leq 0.0001$)The application of the combination dung and NPK gave the number of seeds per pod the highest (5.46 seed/pod) while the control gave the lowest number of seeds per pod. Plants growing on dung gave the best weight of one hundred seeds (56.0g) while the plants sown on the control showed a low weight. Plants growing on the lime and dung plot gave the best harvest index 0.658g. The seed yield varied very significantly (p = *0.0001*) according to these different treatments. The highest yield was obtained when lime combined with NPK was applied (2604.2 kgha^{-1}), lime and cow dung (2604 kgha^{-1}). These applications were followed by Cow dung and Tithonia (2395.8 kg/ha^{-1}) and cow dung at the rate of 30 tha^{-1} (2187.5 kgha^{-1}). The control had the lowest yield (312 kgha^{-1}). Economic analysis showed that the profit is important when we combine Cow dung and NPK 0.05 tha^{-1} (959.02 USD). With (900.48 USD), *Tithonia* 30 tha^{-1} seems to be also an important element economically. Limes combine with cow dung (842.22 USD), and Cow dung and *Tithonia* (850.98 USD) showed also important results (Table 4). Application of mineral fertilizer only on ferralsol is not as much profit as its combination with organic manure as cow dung or *Tithonia*.

3.3. Discussion of Results

3.3.1. Effects of Types and Combination of Fertilizers on the Improvement of Ferralsol Properties

This study showed that a combination of organic manure such as cow dung, fresh biomass of *Tithonia,* and mineral fertilizer like NPK can improve properties of poor ferralsol and then impact positively growth and yield of biofortified climbing beans varieties grown in the east of RD Congo, especially in Walungu territory. Applying lime at the rate of 1.5 t.ha^{-1} allowed pH to rise from 5.1 up to 7.22. P from 30 to 39 ppm and N from 0.30 to 0.36% during the season.

According to the result of [26], improvement of smallholder soil fertility and production can only be possible by using ISFM aspects. In our case, soil pH improvement was observed on all treatments after a season (except for the control and the recommended NPK dose); these treatments have raised the pH of the soil to an acceptable value. These values are within the range of mean values for the availability and assimilation of almost most mineral elements in the soil [26]. [27,28,29] found that Lime and *Tithonia divesifolia* had virtues in the improvement of Physico-chemical properties of the soil, in the production of humus, in the increase of the mobility and the solubility of some mineral elements, in the formation complexes easily mobilized with the mineral elements in the rhizosphere and the intensification of the activity of the microorganisms respectively with the application of lime.

The pH of 5.50 was observed before seeding and increased up to 5.91 (control) and 5.98 for the recommended dose of NPK after sowing, this increase may be due to a drop of leaves during the cropping season. These leaves were decomposed in the soil to raise the pH or the buffering capacity of the soil when an element is in excess in the soil solution and the soil. In our case, the ions H^+ are fixed on the adsorbent complex which directly constitutes the potential acidity. The organic matter affects the ion exchange by improving the pH and affects the sequestration of the Al^{3+} and Fe^{3+} of the soil as well in acidic soil by its buffering capacity and the contributions of nutrients by increasing the CEC at the clay-humic complex. It also promotes the mobilization of various mineral elements and the assimilation of those that are not available in the rhizosphere. [31] found an increase of 6.5 to 7.2 in the south-western of RD Congo in Kasaï province. The application of mineral fertilizer with different types of organic manure showed their efficiency to correct Physico-chemical and properties of ferralsol and positive impact on microbial activity [32,33]. However, in our case, it should be noted that those values may vary the next season because organic matter and lime gradually release phosphorus and other elements contained.

Table 3. Effects of fertilizes type on climbing bean growth and yield parameters

Treatments	**Germination rate (%)**	**Plant Height at Flowering (cm)**	**Plant Biomass**	**Harvest Index**	**Number of Pod per Plant**	**Number of Grain per Pod**	**Weight of hundred grains**	**Yield (kgha^{-1})**
Control	73.80±11.60	97.81±2.33^{g}	25.81±0.10^{f}	0.46±0. 00^{c}	16.5±2.4^{abc}	3.8±0.5^{c}	44.0±3.6^{d}	512.5^{d}
0.150 tha^{-1} NPK	81.63±5.09	128.43±18.07^{e}	28.5±0.98^{e}	0.47±0. 01^{c}	15.5±5.6^{bc}	4.6±0.1^{abc}	48.0±1.7^{bcd}	741.7^{c}
Cow dung 30 tha^{-1}	70.33±27.32	191.23±27.69^{c}	55.2±1.57^{b}	0.65±0.01^{a}	27.1±3.3^{a}	5.13±0.2^{a}	56.0±2.6^{a}	2187.5^{ab}
Limes1.3 tha^{-1}	82.60±13.67	105.81±8.24f^{g}	25.25±1.05^{f}	0.44±0. 04^{c}	11.41±2.8^{c}	3.96±0.5^{bc}	47.3±2.3^{cd}	754.2^{c}
Tithonia 30 tha^{-1}	78.30±4.68	197.39±7.60^{c}	49.0±0.85^{c}	0.60±0.01^{ab}	23.9±1.8^{ab}	4.6±0.2^{abc}	47.3±7.5^{cd}	1958.3^{b}
Limes and cow dung 15 tha^{-1}	70.10±20.67	243.39±33.53^{a}	56.46±0.06^{ab}	0.65±0. 01^{a}	27.66±4.8^{a}	5.3±0.6^{a}	55.33±4.2^{a}	2604.2^{a}
Tithonia and NPK 0.05 tha^{-1}	75.20±13.79	157.36±12.94^{d}	31.18±0.15^{d}	0.48±0. 01^{c}	20.5±3.6^{abc}	4.6±0.1^{abc}	48.3±3.2^{bcd}	1395.8
Limes and NPK 0.05 tha^{-1}	81.90±5.56	122.61±15.63^{ef}	26.36±0.94^{ef}	0.45±0. 03^{c}	18.9±3.0^{abc}	4.8±0.4^{abc}	47.33±3.5^{cd}	1816.7^{c}
Cow dung and NPK 0.05 tha^{-1}	80.03±15.20	222.93±7.60^{b}	58.33±0.83^{a}	0.64±0. 01^{a}	26.2±6.1^{ab}	5.46±0.2^{a}	50.6±1.5a^{bc}	2604.2^{a}
Cow dung and Tithonia 15 tha^{-1}	67.76±4.50	238.86±12.68^{ab}	54.11±0.45^{b}	0.56±0. 01^{b}	22.6±3.8^{abc}	4.90±0.3^{ab}	53.3±1.2^{ab}	2395.8^{ab}
Mean	**76.167**	**170.58**	**41.03**	**0.54**	**21.058**	**4.73**	**49.767**	850
P-value	*0.8971*	*0.0001*	*0.0001*	*0.0001*	*0.0009*	*0.0003*	*0.0073*	*0.001*
HSD		18.717	2.5918	0.0526	11.628	1.0470	10.217	250.4
C.V%	18.89	6.40	2.16	3.30	18.87	7.55	7.00	14.8

Table 4. Efficacy and Profitability of applied treatments

	Applied Quantity				Activities Cost	Cost				AC($)	C.T($)	Yield ($kgha^{-1}$)	PP($)	PT($)	Profit
Treatments	**Limes**	**MF**	**CD**	***Tith***		**C**	**EM**	**EO**	***Tith***						
Control	0	0	0	0	128.7	0	0	0	0	20.8	149.5	312.5	0.6	187.5	***38***
0.150 tha^{-1} NPK	0	100	0	0	128.7	0	158	0	0	20.8	307.5	541.7	0.6	325.02	***17.52***
Cow dung 30 tha^{-1}	0	0	30	0	128.7	0	0	750	0	20.8	899.5	2187.5	0.6	1312.5	***413***
Limes1.3 tha^{-1}	1.3	0	0	0	128.7	433.3	0	0	0	20.8	582.8	354.2	0.6	212.52	***370.28***
Tithonia 30 tha^{-1}	0	0	0	30	128.7	0	0	0	125	20.8	274.5	1958.3	0.6	1174.98	***900.48***
Limes and cow dung 15 tha^{-1}	0.65	0	15	0	128.7	216.6	0	375	0	20.8	720.3	2604.2	0.6	1562.52	***842.22***
Tithonia and NPK 0.05 tha^{-1}	0	0.05	0	15	128.7	0	79	0	62	20.8	290.5	1395.8	0.6	887.48	***546.98***
Limes and NPK 0.05 tha^{-1}	0.65	0.05	0	0	128.7	216.6	79	0	0	20.8	445.5	416.7	0.6	250.02	***195.08***
Cow dung and NPK 0.05 tha^{-1}	0	0.05	15	0	128.7	0	79	375	0	20.8	603.5	2604.2	0.6	1562.52	***959.02***
Cow dung and Tithonia 15 tha^{-1}	0	0	15	15	128.7	0	0	375	62	20.8	586.5	2395.8	0.6	1437.48	***850.98***

Legend: The values of a column with different letters are significantly different at 5% of the probability of the Tukey HSD test. HSD: Honestly Significant Difference of means, MF = mineral fertilizer. CD = Cow dung. Tith = Tithonia. AC= Activities costs. CA = Application cost. TC = Total Cost. Yield = Yield. PP = Product Price. TP = Total production

3.3.2. Effects of Fertilizer Types on Growth and Yield of Climbing Bean Grown on Ferralsol

Fertilizer did not have a significant effect on seed emergence *(p = 0.891)*. In most cases, the rate of emergence depends on the seeds' conditions, moisture, temperature, soil oxygen, and especially the nutrient reserve in the cotyledon. The best-known temperatures for bean germination vary between 26.7°C and 27.3°C, the water requirement between 144.6-152.4 mm water [34]. All these conditions are met by our environment and these have influenced our rate of emergence. The height of the plants at flowering varied very significantly ($p = 0.001$) according to the type of fertilizer. Cow dung with lime combination surpassed the other treatments with an average of 243.39 cm compared to the control.

The high presence of nitrogen in cow dung, fresh biomass of *Tithonia* treatments may explain this result. The organic manure affects very significantly the plant growth compared to the control. Indeed, nitrogen is the most important element of plant life.

[13] showed that the addition of manure to soils fertilized with mineral fertilizers improve their effects on both growth and yield parameter. On the other hand, bean plants fertilized with cow dung had a height of 40 cm compared to 15 cm. The results of [35] show that bean plants fertilized with cow dung presented a high height of 62.30 cm compared to the one from hens 60.50 cm; however, nitrogen excess would lead to exaggerated vegetative growth. The height for the fertilized plot with mineral fertilizer was not high compared with those fertilized with cow dung, *Tithonia*, or their combinations. This phenomenon may be explained either by the effect of the heavy rainfall recorded in this part of the country or the mineral fertilizer that could be solubilized in the soil solution and be leached by rainwater or fertilizer suffered denitrification phenomenon and nitrogen lost into the atmosphere. The observations of [29,31] show that nitrogen loss by leaching or denitrification in moist soil is in the order of 10% in 2 days. 25% in five days and a half after 10 days.

The different treatments significantly influenced the above-ground biomass *(p = 0.001)*, the harvest index ($p = 0.001$), number of pods per plant ($p = 0.0009$), number of seeds per plant pod ($p = 0.0003$), the weight of one hundred seeds ($p = 0.0073$) compared to the control. The most important biomass was obtained on the cow dung associated with NPK fertilizer with an average of 58.33 g. This result can be explained by a complementary presence of nitrogen in both manures; in addition, the organic matter brings other nutrients which are very favorable to the vegetation. According to [1] the improvement of soil structure by organic matter makes nutrient absorption easier; which in turn influences plant growth and development. [35] found that the quantities of biomass produced in plots with NPK and organic manure get greater (967 kg) than those of control plots (592 kg). The lowest biomass was obtained on the control plot. The harvest index (HI) was high on plots where cow dung-lime combination was applied (0.6); it was then increased by increasing phosphorus. This can be explained by the positive effect of lime on the release and availability of soil phosphorus. However, the application of NPK at the 150 $kgha^{-1}$ rates has a significantly higher index (60. 39%) [4]. The different treatments highly influenced the seeds to yield of climbing bean. The highest yield is obtained with the combination of cow dung and NPK and cow dung with lime with an average of 2604.2 $kgha^{-1}$.

This result can be explained by the effect that lime has on the Physico-chemical and biological properties of the soil. It has raised the soil pH towards neutrality through the replacement of the H^{+}, Al^{3+} and Fe^{3+} ions on the adsorbent complex by the exchangeable Ca^{2+}, K^{+}, Mg^{2+} and Na^{+} ions that increase assimilation, solubility, and availability of mineral elements and stimulation of the symbiotic fixation of nitrogen by Rhizobium [22]; it will intervene also in the availability and assimilation of Phosphorus. The result of [29] demonstrates that the yield of cowpea seeds was high with the association of organic matter and lime. In the control, the lack of organic manure inputs is accompanied by a loss of OM and together contributes to the significant decrease in crop yields.

For the economic profitability of the bean crop through the use of mineral fertilizer, organic manure, lime, and their combinations; the results obtained (Table 4) show that treatment with *Tithonia* alone was profitable compared to other treatments; and considering the low purchasing power of most farmers in the study area, the use of 30 t ha^{-1} of *Tithonia*) is the suitable treatment to suggest despite its highest benefit. Similar studies were done in Kenya also showed that the application of 5 $t.ha^{-1}$ of fresh *Tithonia* leaves provided the highest profit margins [7,8].

4. Conclusion

The management of poor ferralsols as visible at Kaziba in Walungu territory, eastern of RD Congo should only be based on the combination of fertilizer types. *Tithonia* is a great asset for improving the availability of soil nutrients and can provide optimal amounts of nutrients needed for growing climbing beans without the use of mineral fertilizers. This is crucial for small farmers in the study area who are poor and have no access to mineral fertilizers and have low purchasing power. The application of lime and NPK made to multiply the yield up to 4.4 and 4.2 for *Tithonia* while mineral fertilizer (NPK) only allowed an increase up to 1.44. The combination of different types of fertilizer (organic, mineral, and liming) is essential to improve not only the Physico-chemical properties of the ferralsols but also the growth and yield of the biofortified climbing bean. However, other studies are needed to quantify the durability of this effect.

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