



Research Article

Effects of tillage methods and organic manure sources on yam production in Kisangani

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Abstract

Low soil fertility, high chemical fertilizer costs, and suboptimal tillage significantly constrain yam yield in Kisangani. This study evaluated the effects of tillage methods and organic manure on yam production. Three tillage methods (zero tillage, mounds and ridges) and three organic manure treatments (no manure, cow dung and pig droppings) were evaluated in a split-plot design, with tillage methods assigned to the main plots and organic manure treatments assigned to the subplots. The experiment was replicated four times across two sites, and key vegetative and tuber yield traits were evaluated. The results indicated that while mini-set recovery exceeded 95% across all treatments and was not significantly affected by the factors studied, growth (neck diameter) and tuber morphological traits (number, length, diameter, and weight) exhibited significant ($p < 0.05$) main effects from both tillage and manure types. Soil tillage (mounds and ridges) consistently led to superior plant vigor and larger tubers compared to zero tillage. Pig droppings generally outperformed cow dung in enhancing these parameters. Crucially, the highest overall yam yield of 19.2 t/ha was achieved with the synergistic combination of ridges and pig droppings, which also produced the highest average tuber weight (1.92 kg). Conversely, zero tillage without manure resulted in the lowest productivity. These findings demonstrate that optimizing tillage through ridging, combined with nutrient-rich organic manures like pig droppings, can significantly improve yam production and bridge the yield gap in Kisangani. This integrated approach offers a sustainable strategy for local farmers to maximize profitability and food security, providing a practical alternative to expensive chemical inputs in the Tshopo province.

1. Introduction

Yam (*Dioscorea* spp.) is a vital staple food and income source, especially in tropical and subtropical regions. Its global food production, estimated at 71 million tonnes in 2017 [1], makes it a crucial food security crop, second only to cassava among tuber crops [2]. Yams are an essential food resource across Asia, South America, and particularly West Africa, where they are

deeply integrated into the dietary patterns and livelihoods of millions [3]. In countries like Côte d'Ivoire, it forms a significant part of the daily diet, with approximately 80% of the production intended for self-consumption [4]. Beyond its nutritional value, yam holds profound socio-cultural importance, often featuring prominently in local rituals, weddings, and

annual festivals, underscoring its unique significance that extends beyond that of other crops in tropical environments [5]. Thus, yam contributes substantially to stabilizing food systems and enhancing the predictability of farmer incomes [6]. It has also emerged as an important cash crop that supplies urban markets and exhibits remarkable price stability compared to cereals during international market crises [7].

In the Democratic Republic of Congo (DRC), yam is a key tuber crop with enormous potential for food security and poverty alleviation, ranking as the third most consumed tuber crop after cassava and sweet potato [8]. It plays a critical role in filling hunger gaps during lean periods and providing income, with an informal market often dominated by women traders, whose income is crucial for family needs [9]. In the eastern DRC, including areas around Kisangani, yam is highly valued for its cultural, therapeutic virtues, and its role as a cash crop in local urban markets [8]. Despite this, yam is often an under-represented and neglected crop in the country, with stagnant yields averaging around 4.3t/ha, a mere tenth of its potential yield in Africa [10]. This substantial yield gap is further complicated by a lack of significant genetic improvement, leading to its gradual substitution by other staple crops like cassava, sweet potato, and maize [8].

Yam production faces considerable constraints, and research efforts dedicated to this crop have historically been limited, leading to its classification as an "orphan crop. Cornet *et al.* [11] starkly highlighted this disparity, noting that the number of publications on yam in 2013 roughly matched those on potato from four decades prior. In the DRC, this research deficit is most evident in the areas of soil fertility and land preparation, both of which remain major barriers to higher yields [12]. Furthermore, farmers face constant pressure from declining soil health, water stress, and a variety of pests and diseases, such as those caused by from viruses, fungi, and nematodes. These challenges do more than lower food production; they prevent farmers from earning a steady income and place a particularly heavy burden on rural women [13].

Current yam yields in typical farming environments

remain critically low, averaging approximately 12 t/ha across major African production zones, and often dropping below 10 t/ha in regions like Burkina Faso [14, 15]. This is a fraction of the estimated yield potential, which can reach nearly 50 t/ha, particularly for *Dioscorea alata* [13]. While this substantial yield gap is exacerbated by declining soil fertility in West Africa [16] and the inherently low-fertility soils of the DRC [17], it is also heavily influenced by interspecific and varietal differences.

Yield variations across these regions are a product of both environmental constraints and the specific genetic potential of the species cultivated, as different yam species and local landraces respond uniquely to soil nutrient availability and management practices. Soil depletion is a major ecological factor hindering yam production in eastern DRC (68.3%) [8], and yam, being a demanding crop, is traditionally planted as the first crop after a long fallow period [18]. Yam cultivation, especially under traditional practices, can contribute to soil degradation, leading to a vicious cycle of decreasing yields in rural areas.

To bridge this yield gap and achieve sustainable yam production in a system where minimal to zero tillage is mostly used, the adoption of improved production techniques is paramount. Tillage methods and the judicious application of organic manure represent promising avenues. Research has consistently demonstrated that appropriate tillage is a fundamental prerequisite for successful yam cultivation, directly impacting tuberization and root development [19]. In the DRC, traditional cultivation techniques (minimal tillage) remain a significant constraint on productivity [12].

Research on similar root crops, such as cassava, has demonstrated that mound and ridge seedbed preparations significantly outperform flat planting. Although flat planting is common, it results in the lowest yields due to poor soil drainage and aeration [20]. As yam requires loose, well-aerated soil for tuber expansion, effective tillage is essential for high production [8]. Specifically, studies in the DRC have shown that ridges produce tubers with superior length and diameter compared to both mounds and untilled plots [8].

Numerous studies have confirmed that yam yields

increase significantly when tillage methods are combined with organic manure application [21, 22]. While many farmers prefer chemical fertilizers, the abundance of organic manure in Kisangani provides a valuable and locally accessible resource for sustainable soil management [23]. Organic matter is crucial for enhancing the physicochemical and biological properties of soil, which are essential for long-term productivity [24, 25]. Given the economic importance of yam in the DRC and the existing yield gaps in Kisangani, there is a clear need for Integrated Soil Fertility Management (ISFM), an approach that combines improved germplasm, fertilizer, and local organic resources with good agronomic practices. Therefore, this study aimed to determine the optimal combination of tillage method (tillage) and organic manure application. Our objective was to identify the specific management practices that maximize yam production under the prevailing environmental conditions in Kisangani.

2. Materials and methods

2.1. Description of experimental location

The study was conducted at two distinct experimental sites located in the peri-urban areas of Kisangani. The first site was situated along the Buta axis at an approximate distance of 8 km (0°34'05.6" North latitude and 25°13'31.0" East longitude), while the second was along the Yangambi axis, approximately 11 km from the city center (0°32'31.0" North latitude and 25°06'05.5" East longitude). The climatic conditions at these sites are characteristic of Kisangani, which is classified as an Af type climate under the Köppen system. This climate is typically distinguished by average temperatures hovering around 25°C, with abundant annual precipitation averaging 1800 mm. Rainfall is distributed throughout the year, marking two primary seasons: a pronounced rainy season and a relatively short, less humid period extending from late March to June [26]. The relative humidity in the region consistently ranges between 80% and 90% [27]. Kisangani's native vegetation is characterized by dense rainforest ecosystems.

The geological foundation of the soils in Kisangani is classified within the Lindian system, dating back to

the Upper Precambrian period [28]. The underlying bedrock is primarily composed of red sandstone, schist, and quartz, with overlying soils formed from clayey-sandstone layers. The decomposition of this sandstone and the associated overburden formations has predominantly led to the development of sandy soils across the region. The broader floristic diversity of Kisangani, corresponding to the Tshopo province, is notably rich, with an estimated 2600 plant species [29, 30]. At the commencement of the experiments, the specific land area used for the study was under a short-term grassy fallow, having been cultivated with *Manihot esculenta* (cassava) and *Zea mays* (maize) in the preceding cropping season. The soil was sandy (72% sand) and strongly acidic (pH 5.06), which is typical of Kisangani Ferralsols. Although total nitrogen (0.94%) and phosphorus (0.11%) levels were low, the high initial potassium levels (12.12%), supplemented by organic manure, created a favorable environment for optimal yam tuberization. The dominant plant species observed on these fallowed lands included *Panicum maximum*, *Cynodon dactylon*, *Pueraria javanica*, *Digitaria occidentalis*, *Commelina diffusa*, *Elaeis guineensis*, and *Spermacoce latifolia*.

2.2. Plant material, tillage, and organic manure

The plant material utilized in this study was sourced from predominantly cultivated local landraces in the DRC, especially in major yam producing areas (Lisala, Bumba, and Kisangani). The landrace from which the planting material was obtained is particularly known for its high preference among households. Commercially available cattle manure and pig droppings were used as soil amendments in the organic manure treatments. Both organic amendments were applied at a rate of 4 kg/m². While cattle manure provided slightly higher inputs of N (126.8 g/m²) and P (27.11 g/m²), pig droppings were characterized by a superior potassium supply (160 g/m²), doubling the input of cattle manure (80 g/m²). The high potassium concentration in pig droppings is a key factor in meeting the high potash requirements for yam tuberization and optimizing the yield. The experimental design for tillage incorporated three distinct methods: traditional mounds, ridges, and zero-tillage.

2.3. Experimental design and treatments

The study employed a split-plot design organized in a Randomized Complete Block Design (RCBD) with four replications. The main-plot factor consisted of three tillage methods: zero tillage, mounds, and ridges. Within each main plot, the sub-plot factor consisted of three organic manure treatments: no-manure (control), cow dung, and pig droppings. This resulted in nine distinct treatment combinations (Table 1).

Table 1. Treatment structure combining three tillage methods and three organic amendments used in the study.

S/N	Code	Treatment structure
1	L1F1	Zero tillage without manure
2	L1F2	Zero tillage cow dung
3	L1F3	Zero tillage pig droppings
4	L2F1	Mounds without manure
5	L2F2	Mounds with cow dung
6	L2F3	Mounds with pig droppings
7	L3F1	Ridges without manure
8	L3F2	Ridges with cow dung
9	L3F3	Ridges with pig droppings

The total experimental area was 1,624 m² (56 m × 29 m). The field was divided into four blocks (replicates). Within each block, the three tillage methods were randomly assigned to the main plot. Each main plot (measuring 108 m²) was then subdivided into three sub-plots of 36 m² (6 m × 6 m). The three organic manure treatments were randomly assigned to the sub-plots within each main plot. Plant spacing was maintained at 1 m × 1 m, consistent with the standard yam trial protocols. Each sub-plot contained 36 plants (6 rows × 6 plants per row). With a total of 36 sub-plots across the entire experiment (9 treatments × 4 replications), the total population was 1,296 plants. A single local yam landrace was used throughout the study to ensure a uniform response to soil treatments.

2.4. Preplanting and planting operation

Yam tubers were first prepared by cutting them into 200 g mini-sets. Care was taken to ensure that each mini-set retained sufficient skin (bark) and at least one viable eye or bud, which is crucial for successful sprouting. To mitigate potential attacks from bioaggressors, these tuber mini-sets underwent a protective treatment by soaking for 10 min in a wood ash solution made from dissolving wood ash from

locally available plant biomass in water. Following treatment, the mini-sets were air-dried for 24 h under a protective cover. They were later placed in a propagator at the IFA/Yangambi for pre-germination. Sprouting typically began after two weeks, and the process was completed after approximately one month and one week. The experimental fields were meticulously prepared concurrently with the germination process. This involved delimiting the plots, thoroughly clearing the existing vegetation, and incinerating it. Ploughing was conducted two weeks before planting to achieve a more even distribution of plant debris and promote optimal soil fragmentation [31]. For the tillage treatments, mounds were created as raised heaps of soil, reaching a height of 30 cm and a diameter of 1 m. This traditional technique, common for root and tuber crops like sweet potato, yam, and cassava across tropical Africa, aims to provide an optimal growing environment for tuber development [32]. In contrast, ridges were formed as continuous raised beds, measuring between 20 to 30 cm in height and extending for a length of 6m along the plots.

2.5. Planting and field maintenance, and trait phenotyping

Planting was conducted simultaneously across both experimental sites between April 25 and May 5, 2024. Following planting, a series of essential field management operations were undertaken. These included plot labeling, staking to support vine growth, routine weeding, and the application of animal manure according to the specifications in the experimental design. For weeding, manual weeding was performed four times throughout the growing season, with the frequency determined by the observed weed cover in each plot. For the staking operation, stakes were installed approximately eight weeks after planting to facilitate proper vine development. Harvesting commenced eight months after planting, a timing determined by the visible senescence and drying out of the yam plant leaves, indicating tuber maturity. Observations were systematically collected for both the growth and tuber production parameters. The growth parameters included the mini-set recovery rate and neck diameter in mm. Tuber production parameters encompassed the average number of tubers per plant, tuber length

Table 2. Chemical composition of cow dung and pig droppings in percentage.

Type of manure	C/N	pH	C	N (g)	P (g)	K (g)
Cattle Manure	11.21	7.49	35.56	3.17	0.679	2.22
Swine Manure	9.9	7.5	29.70	3.06	0.581	3

Legend: C/N=Carbon-Nitrogen Complex; C=Carbon; N=Nitrogen; P=Phosphorus and K=Potassium.

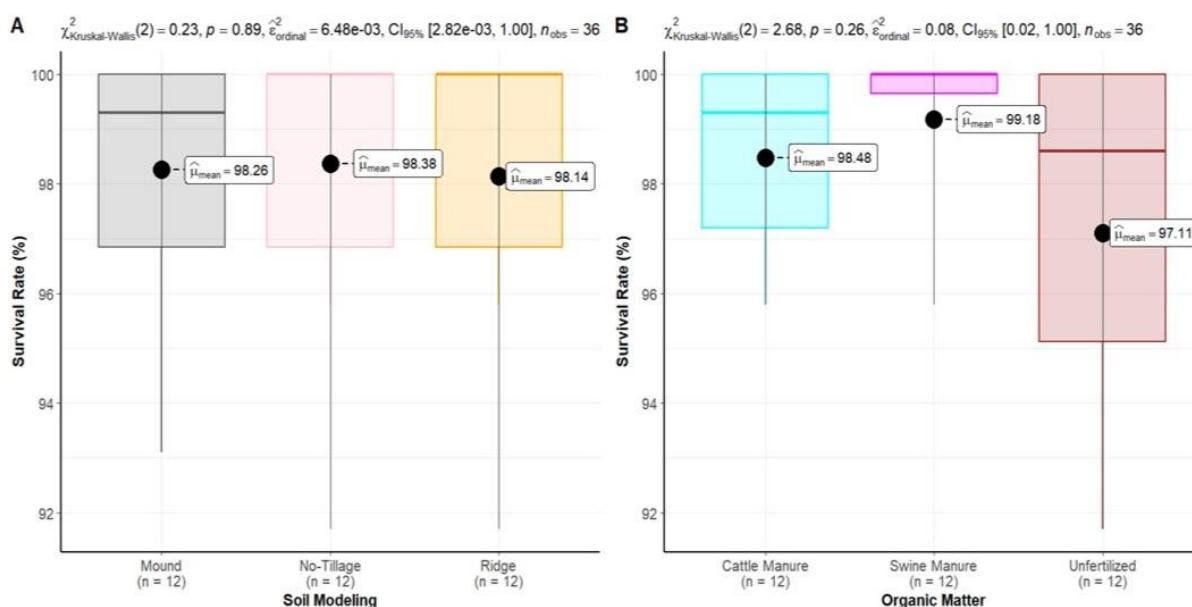


Figure 1. Mini-set recovery rate (A) under three different tillage methods, (B) under three different manure treatments.

in centimeters (cm), tuber diameter in centimeters (cm), tuber weight in kilograms (kg) from where tuber yield in ton per hectare (t/ha) was calculated. Harvesting commenced eight months after planting, a timing determined by the visible senescence and drying out of the yam plant leaves, indicating tuber maturity.

2.6. Statistical analyses

All collected data were subjected to statistical analyses using R software version 4.2.0. A two-factor analysis of variance (ANOVA) was conducted to assess the significance of differences between treatment means. Subsequently, mean comparisons were performed using Tukey’s HSD post-hoc test at a 5% significance threshold ($p < 0.05$). Data tabulation and graphical representations for visualization were prepared using Excel.

3. Results

3.1. Chemical composition of organic manure

The chemical composition of the organic manure is

shown in Table 2. Cow dung had a slightly higher C/N ratio (11.21) than that of pig manure (9.9). The nitrogen (N) content in cow dung was slightly higher than that in pig droppings.

3.2. Mini-set recovery rate and plant growth (neck diameter)

The results revealed non-significant ($p > 0.05$) effects of tillage methods, organic manure treatments, and their interaction on the mini-set recovery rate. The average number of mini-sets recovered for each tillage method was consistently above 95 %. Although zero tillage numerically resulted in a slightly higher recovery rate, this difference was not statistically significant compared to mounds and ridges (Fig. 1A). Similarly, among the organic manure types, pig droppings showed a numerically higher average mini-set recovery rate, but this was statistically similar to that of cow dung and the no manure treatment (Fig. 1B).

Contrary to the mini-set recovery rate, highly significant main effects of tillage methods ($p < 0.0001$),

Table 3. Neck diameter of yam variety evaluated under three different tillage methods and three different organic manure sources.

Soil modes	No-Tillage	Cattle Manure	Swine Manure	p < 0.001
No-Tillage	4.80 ^c	4.84 ^{bc}	4.97 ^{bc}	4.90±0.19 ^b
Mound	5 ^{bc}	6.44 ^{ab}	7.27 ^a	6.09 ±0.19 ^a
Ridge	5.30 ^b	6.06 ^{ab}	6.91 ^{ab}	6.23±0.20 ^a
p < 0.001	5.06±0.19 ^b	5.78±0.19 ^a	6.38±0.19 ^a	p < 0.001

Values with same letters are statistical similar and different from values with different letter at p < 0.001.

organic manure treatments ($p < 0.0001$), and a highly significant interaction effect between tillage methods and organic manure application ($p < 0.001$) were observed on neck diameter (Table 2). For tillage methods, mounds produced the largest average neck diameter (6.23 mm), followed by ridges (6.09 mm), with the zero-tillage method yielding the smallest (4.90 mm). These differences were statistically significant ($p < 0.0001$). For organic manure treatment, pig droppings resulted in a numerically slightly higher average neck diameter (6.29 mm), followed by cow dung (5.68 mm), and no-manure plots (5.20 mm). Statistical analysis confirmed these significant differences ($p < 0.0001$). Post-hoc tests indicated significant differences between pig droppings and cow dung ($p < 0.01$), and between cow dung and no-manure plots ($p < 0.03$). The interaction between tillage methods and organic manure significantly influenced neck diameter. The highest neck diameter (9.14 mm) was recorded for mounds combined with pig droppings. Conversely, the smallest diameter (4 mm) was observed under the zero-tillage and no-manure combination. Organic amendments generally increased stem diameter compared to no-manure under zero-tillage treatment. Mounds consistently proved to be the most appropriate tillage method, showing good results even without manure and performing best when associated with any manure type. Among the organic manures, pig droppings generally outperformed cow dung (Table 3).

3.3. Number of tuber harvested

Soil tillage method had a statistically significant impact on the number of tubers harvested per plant ($p < 0.05$), whereas application of organic manure did not show a significant effect ($p > 0.05$). Specifically, both the ridge (1.29) and mound (1.28) methods produced a significantly higher number of tubers per plant

compared to no-tillage method (1.18). This suggests that the loose soil structure provided by ridging and mounding is essential for maximizing tuber initiation and development in this environment (Table 4).

In contrast, the variation in tuber numbers across the manure treatments was minimal and statistically insignificant. Although Swine manure (1.27) and the no-tillage control (1.26) showed slightly higher numerical values than Cattle Manure (1.23), the lack of a significant p -value indicates that organic fertilization did not influence the quantity of tubers produced per plant in this experiment. Consequently, the results imply that physical soil preparation is a much stronger driver of tuber multiplication in yam than the short-term application of organic amendments, which may influence tuber size (weight) rather than the total number of initiated tubers.

3.4. Tuber length

For tuber length, it showed significant ($p < 0.05$) differences among treatments for average tuber length per plant as a function of both tillage methods and organic manure treatment. However, the interaction between tillage methods and manure treatment on tuber length was not statistically significant ($p < 0.6406$) (Table 5). Mounds (22.21 cm) and ridges (20.73 cm) resulted in significantly longer tubers compared to zero tillage (17.14 cm). Post-hoc tests showed significant differences between mounds and zero tillage ($p < 0.001$), and a similar trend between mounds and ridges, and between ridges and zero tillage ($p < 0.001$). Organic amendments positively influenced tuber length. Pig droppings produced the longest average tubers (22.26 cm), followed by cow dung (20.16 cm) and no-manure plots (17.78 cm). Post-hoc tests revealed significant differences between pig dropping and cow dung ($p < 0.05$), and significant differences between cow dung

Table 4. Number of harvested tuber per plant from yam variety evaluated under three different tillage methods and three different organic manure treatments.

Soil Modeling		Organic Matter	
Tillage	Number of tubers	Manure treatment	Number of tubers
No-Tillage	1.18 ^b	No-Tillage	1.26 ^a
Mound	1.28 ^a	Cattle Manure	1.23 ^{ab}
Ridge	1.29 ^a	Swine Manure	1.27 ^a
<i>p</i> <value	0.0124*	<i>p</i> <value	0.6757ns

Values with same letters are statistical similar and different from values with different letter.

Table 5. Tuber diameter from yam variety evaluated under three different tillage methods and three different organic manure treatments.

Tillage method		Organic manures	
Soil modeling	Tuber diameter (cm)	Organic Matter	Tuber diameter (cm)
No-Tillage	9.60 ^b	No-Tillage	9.70 ^b
Mound	12.25 ^a	Cattle Manure	12.00 ^a
Ridge	11.87 ^a	Swine Manure	12.01 ^a
<i>P</i> <value	0.0000***	<i>P</i> <value	0.0000***

Values with same letters are statistical similar and different from values with different letter at $p < 0.001$.

and no-manure plots ($p < 0.05$) (Fig. 2A-B).

3.5. Tuber diameter

The results indicated significant ($p < 0.05$) differences among treatments for tuber diameter due to tillage methods, organic manure treatment, and their interaction. Mounds (12.25 cm) and ridges (11.87 cm) produced larger tubers compared to zero tillage (9.60 cm). Pig droppings resulted in a higher average tuber diameter (12.01 cm), followed by cow dung (12.00 cm), with the lowest average observed in no-manure plots (Table 5).

3.6. Tuber weight

Both tillage methods and organic manure as well as their interaction effects had significant effects, on the average weight of tubers ($p < 0.001$). For tillage methods, Ridges yielded the highest average tuber weight (1.466 kg), followed by mounds (1.19 kg), with the lowest average (0.784 kg) recorded in zero-tillage plots. For organic manure treatment, pig manure resulted in a higher average tuber weight (1.37 kg) compared to cow dung (1.19 kg) and no-manure (Fig 3A-B). The interaction between tillage methods and organic manure significantly influenced the average tuber weight per plant ($p < 0.0070$). The combination of ridges with pig droppings was the most efficient, yielding the highest average tuber weight (1.92 kg). Other combinations with interesting averages

included mounds with pig droppings (1.28 kg), mounds with cow dung (1.32 kg), and ridges with cow dung (1.5 kg). The zero tillage treatment without manure application yielded the lowest average tuber weight (0.68 kg) (Table 6).

Table 6. Interaction effect of three different tillage methods and three different organic manure treatments on tuber weight of yam.

Tillage methods	No-Tillage	Cattle Manure	Swine Manure
No-Tillage	0.68 ^e	0.80 ^{of}	0.88 ^d
Mound	0.96 ^{cd}	1.28 ^{bc}	1.32 ^{ab}
Ridge	0.96 ^{cd}	1.5 ^b	1.92 ^a

Values with same letters are statistical similar and different from values with different letter.

3.7. Tuber yield

The evaluation of tuber yields revealed significant differences among the tested tillage methods and organic manure ($p < 0.001$), as well as the interaction effect ($p < 0.001$). Similar to the yield related traits, ridges significantly outperformed mounds and later outperformed zero tillage. From the interaction effect, the highest yield was obtained from ridges combined with pig droppings (19.2 t/ha), followed by ridges combined with cow dung (15 t/ha). Mounds with pig droppings (13.2 t/ha) and cow dung (12.8 t/ha) also

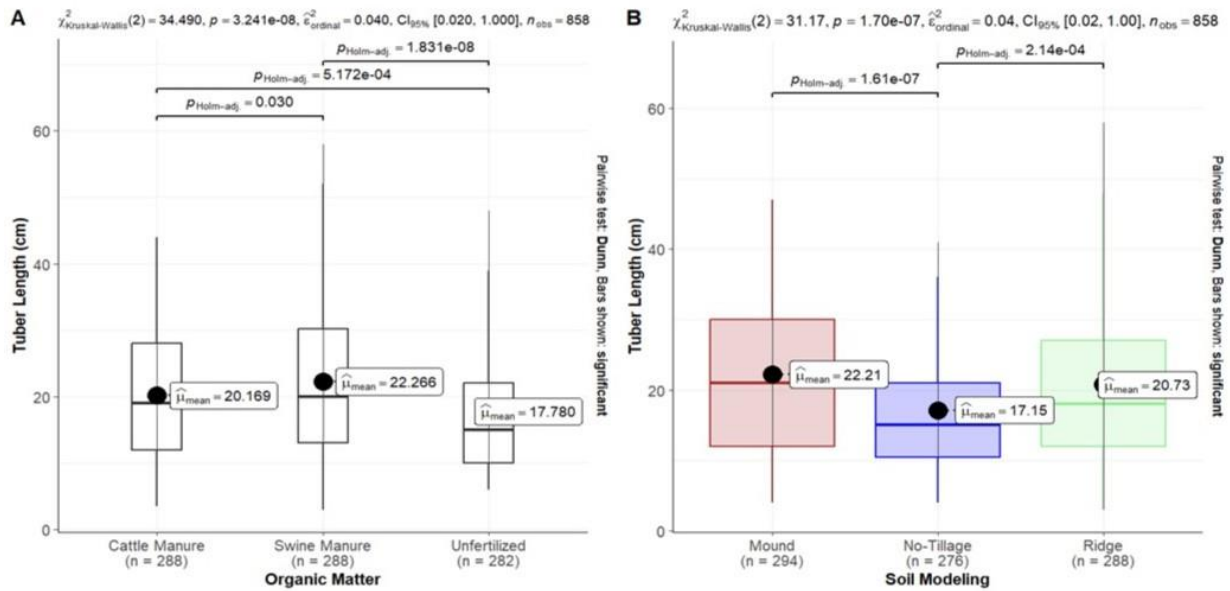


Figure 2. Tuber length (A) under three different manure treatments, (B) under three different tillage methods.

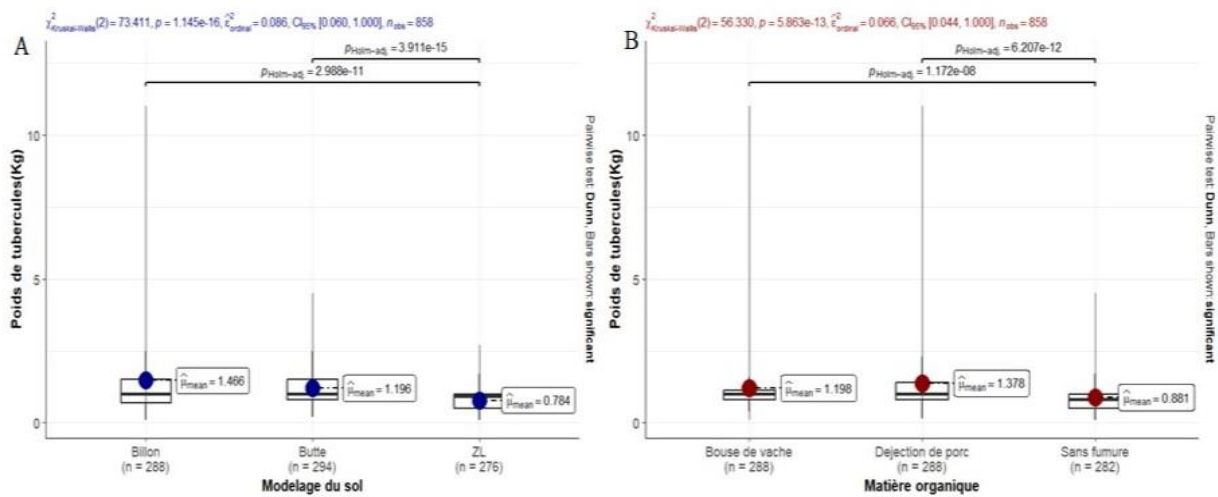


Figure 3. Tuber weight (A) under three different tillage methods, (B) under three different manure treatments.

presented interesting values. The lowest yield (6.8 t/ha) was recorded for the combination of zero-tillage and no-manure (Table 7).

4. Discussion

Our study investigated the impact of different tillage methods and organic manure applications on the growth and production of yam, contributing valuable insights into optimal cultivation practices in Kisangani. Our findings reveal the crucial interplay between soil management strategies and nutrient amendments in enhancing the yam productivity.

Table 7. Interaction effect of three different tillage methods and three different organic manure treatments on tuber yield (t/ha) of yam.

Tillage methods	No-Tillage	Cattle Manure	Swine Manure
No-Tillage	6.8 ^f	8 ^{ef}	8.8 ^{of}
Mound	9.6 ^d	12.8 ^c	13.2 ^c
Ridge	9.6 ^d	15 ^b	19 ^a

Values with same letters are statistical similar and different from values with different letter.

4.1. Effects of tillage methods and organic manures on mini-set recovery

The number of recovered plants obtained was very

good, given that there was a breaking of dormancy of the tubers used for planting. We believe that the quality of the propagation material and the good cultural period (abundant rainfall) are the major driver for this observation. A similar observation was reported by [33, 34]. In addition, [35] reported similar findings on the growth and yield of yam (*D. cayenensis*) in an agro-ecological zone of the D.R.C.

4.2. Effects of tillage methods and organic manures on neck diameter

The tillage methods strongly influenced the neck/collar diameter, mounds produced plants with larger neck diameters as a measure of plant vigor than ridge and zero tillage. The larger neck diameter observed in plants established on mounds could be explained by the large volume of improved soil exploited by this tillage method. In addition, the quantity of nutrients, conservation, and availability of soil water made available to the plants by this tillage method also contributed to the larger neck diameter. Similar results have been reported previously [35, 36].

Regarding the effects of organic manure treatment on this growth parameter, pig droppings differed from other amendments and resulted in plants with larger neck diameters. [37] compared similar organic manures applied in this study in Caribbean cabbage and reported that plant vigor and leaf size increased under pig droppings compared to cow dung, regardless of the quantity applied. The better performance of pig dropping over cow dung and no-manure could be explained by the faster decomposition rate of nutrients. Dibi *et al.* [38] suggested that the evolution of stem diameter is proportional to the size of the mini-fragments, the duration of yam cultivation and variations.

4.3. Effects of tillage methods and organic manures on the average number of tubers harvested

The number of tubers harvested varied from one to two in all treatments. The presence of two tubers per plant was more frequent in plots with ridges than in those with mounds and zero tillage. For organic manures, pig droppings produced more than two tubers per plant harvested. In addition, the length and size of tubers harvested per plant under pig droppings were equally better compared to cow dung and no-manure plots. Pouya *et al.* [39] reported similar

observations on the combined effects of the type of soil cultivation, fertilization options and the date of emergence of the plant on the growth and yield of yam in Burkina Faso. Studies conducted by Molongo *et al.* [35] in the DRC similarly reported two to three tubers harvested per plant using improved soil tillage methods. This better performance of pig dropping over cow dung could perhaps be explained by high bacterial activity. Pigs depend on an omnivorous diet, which enriches their droppings with nutrients such as phosphorus, nitrogen and especially potassium, which are mobilizing elements of photosynthesis. These elements are responsible for the translocation of carbohydrates from the leaves to the tubers in absorbable forms (ions) by the plants.

4.4. Effects of tillage methods and organic manures on tuber diameter

Tillage methods also influenced tuber diameter. Among the methods used, mounds were found to be the most suitable for yam production. Our study revealed that even if mounds were not combined with organic manure, they presented an interesting observation with respect to tuber diameter. They were better than ridges and zero tillage. This performance could be due to their ability to offer plants a larger soil exploitation volume and conserve organic matter and soil water for gradual release to the plant for usage. Mounds improve water infiltration and limit surface runoff. Mound was followed by ridges in effect on tuber diameter, and the interaction of these two tillage methods with pig droppings provided the largest tuber diameter. [40] and [41] reported similar findings, with mounds providing better weed control and soil water conservation compared to ridges. In addition, Pouya *et al.* [39] reported a similar finding in a study on the combined effect of tillage type, fertilization options and seedling emergence date on yam growth and yield in Burkina Faso. The author found that any fertilizer application, regardless of the option, significantly increased the average tuber mass compared to the control on mounds.

4.5. Effects of tillage methods and organic manures on tuber length

The average length was affected by the organic amendments and tillage methods. Plants from plots receiving pig manure with ridges and mounds

produced longer tubers. These observations are consistent with the findings that for yam, tuber elongation is progressive from one to six months and either plateaus or decreases thereafter, because at this time, the plant reaches the full period of tuber elongation and development. Beyond this period, tuber bulking is the main activity. All organic matter for plant development is mobilized for tuberization [35].

4.6. Effects of tillage methods and organic manures on tuber weight

Tuber weight is an important parameter for assessing yam production and productivity. It is a direct measure of yield. Both tillage methods and organic manure treatments affected tuber weight. Ridge and mound produced heavier tubers and when combined with pig droppings equally produce the fascinating outcomes for tubers weight. Contrary to the observations from ridge and mound, zero tillage without organic manure could not produce ware or market sized yam tubers. Our observation slightly contradicts that those of [42] in Nigeria, who reported significantly higher yields on mounds compared to ridges and no-till. In addition, a beneficial effect of organic amendments on yam production was also reported [43, 44]. Organic manure increases the organic matter components of the soil, thereby promoting the absorption of mineral elements, particularly nitrogen and water, by plants consequently increasing utilization efficiency [45]. Finally, it also improves the soil physical properties which is a major determinant of water and mineral retention capacity.

4.7. Effects of tillage methods and organic manures on yield

Similar to tuber weight, ridges with organic manure (pig dropping and cow dung) produced the highest yield in the study, followed by mound and organic manure. From a general perspective, ridge was the most suitable tillage method and pig droppings was the best organic manure treatment for our study particularly when tuber yield is paramount. Our observation contradicts those of reported [46, 47] combination of mound and pig dropping which is the best tillage method and organic manure treatment for optimizing yam production. However, our findings do not agree with the aforementioned authors, and

the findings from other researchers [37, 44, 48] corroborate our observations.

5. Conclusions

This study conclusively demonstrated that both tillage methods and the application of organic manure significantly influenced yam growth and production parameters under Kisangani soil conditions, with a notable interaction effect observed for several key traits. While mini-set recovery was robust across all treatments, tillage/tillage methods (mounds and ridges) consistently enhanced neck diameter, tuber length, tuber diameter, and tuber weight compared to zero tillage. Among the organic manure/amendments, pig droppings generally outperformed cow dung, leading to superior growth vigor and heavier tuber weight. Critically, the highest overall yam tuber yield (19.2t/ha) was achieved with the synergistic combination of ridges and pig droppings. These findings underscore the importance of tailored agronomic practices, highlighting that integrated soil management, specifically the use of ridging coupled with nutrient-rich organic manures such as pig droppings, is crucial for maximizing yam productivity and potentially bridging the yield gap in similar agro-ecological zones of the DRC. This study provides practical recommendations for farmers to optimize yam cultivation and contributes to food security efforts in the region. We suggest that this study be continued to evaluate the response of the two most widely cultivated yam species in the Kisangani region, such as *Dioscorea cayenensis* and *Dioscorea alata* and assess the residual effect of the organic fertilizers applied on the performance of these crops.

Disclaimer (artificial intelligence)

Author(s) hereby state that no generative AI tools such as Large Language Models (ChatGPT, Copilot, etc.) and text-to-image generators were utilized in the preparation or editing of this manuscript.

Authors' contributions

Conceptualized the study, supervised and drafted the original manuscript, D.M.A.; selection of software tools for data processing and performed the translation as well as the linguistic revision (French to English) of the manuscript. I.I.A.; statistical analysis,

data processing and data visualization (graph design), J.P.A.; development and selection of the experimental methodology, A.P.; methodological development, data interpretation, editing and revision. J.C.M.

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Availability of data and materials

All data will be made available on request according to the journal policy.

Conflicts of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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