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# Vermicompost application rate and timing for optimum productivity of onion (*Allium cepa* L.)

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**Key words:** Vermicompost application rate, Application timing, Onion, Sandy-silty soil, Sandy-clay soil

**Abstract**

Increasing food resources sustainably remains today one of the fundamental options to trigger prosperity in developing countries. Vermicompost, which is a potential soil fertilizer for sustainable agriculture has proven to increase yields of a variety of crops, but little is known about its application rate and timing for optimum productivity of onion in Africa. This field study investigated different vermicompost application rates, before transplanting and at bulbing, on onion growth and productivity. The respective applications were performed via a complete randomized block design, each at three replications, during three-season cycles on sandy-clay and sandy-silty soils. Results showed that the highest yield (19.8 t ha$^{-1}$), on sandy-clay soil, was obtained at 20 t[vermicompost] ha$^{-1}$ spread before transplanting, which was 7.9, 1.3, 0.4, and 1.6 times higher than yields obtained, respectively, with the control, 30 t[vermicompost] ha$^{-1}$, 40 t[vermicompost] ha$^{-1}$ and mineral fertilizer. On sandy-silty soil, the highest yield (7.33 t ha$^{-1}$) was obtained at 30 t[vermicompost] ha$^{-1}$ applied before transplanting, and was approximately 4.9, 1.6, 2.0, and 1.7 times higher than yields obtained with the control, 20 t[vermicompost] ha$^{-1}$, 30 t[vermicompost] ha$^{-1}$, 40 t[vermicompost] ha$^{-1}$, and mineral fertilizer, respectively. The application rate and timing of vermicompost, clearly, had influences on onion productivity and were functions of soil type. Vermicompost performed better on sandy-clay soil than on sandy-silty soil. Onion production on sandy-clay soil with vermicompost application rate of 20 t ha$^{-1}$ resulted in the optimal onion yield. Onion productivity was adversely affected by over-application of the vermicompost.

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## Introduction

Faced with growing world population, increasing agricultural productivity in a sustainable manner is still a challenge. In West Africa, onion is the third most vegetables grown after capsicum peppers and tomatoes (FAO 2012). In fact, Onion (*Allium cepa* L.) is one of the most important commercial spice crops of the world belonging to the Amaryllidaceae family (Hossain *et al*., 2017). It is an important constituent of many typical African dishes and is consumed daily in most households, as fresh leaves, dried leaves and, mainly, as dry bulbs (Liguori *et al*., 2017). Recent reports suggest that the use of onion as a traditional medicine stems from its 11 constituent amino acids, which are key to heart and cancer diseases prevention because of their anti-inflammatory, anti-cholesterol, aphrodisiac, and antioxidant properties (Nicastro *et al*., 2016).

The world's onion-bulbs annual production was estimated at about 85.5 million tons in 4.3 million ha compared to only approximately 0.57 million ha of the total cultivated land in Africa (FAO 2012). The productivity of onion in Africa is around 14.5 t $ha^{-1}$, which is significantly lower than the world average yield of 19.9 t $ha^{-1}$(FAO 2012). However, regional production is not adequate to satisfy the needs of the consumers for the whole year, and huge quantities of onions have to be imported from Europe and Asia (RONGEAD and CHIGATA 2015). In Côte d'Ivoire, for instance, the annual demand for onions in 2015 was about 115,000 t, while domestic production was only about 4,500 t (RONGEAD and CHIGATA 2015). Because of this huge deficit, Côte d'Ivoire was the largest onion importer in West Africa during this same period importing more than 50,000 t[onion] per year (RONGEAD and CHIGATA 2015). In this context, Côte d'Ivoire spends about US$75 million every year to import onions from Holland, China, etc. To address this imbalance, Côte d'Ivoire government now supplies free inorganic fertilizers and pesticides to promote onion production in order to limit importation. The foregoing government initiative has increased onion cultivation from 23 to 160 ha in only three years (RONGEAD and CHIGATA 2015). Despite this push, the country has not reached half of its target onion cultivation. The low onion hectarage is exacerbated further by the low onion productivity in Côte d'Ivoire, which is just 10 $t.ha^{-1}$ (RONGEAD and CHIGATA 2015).

To meet the onion national demand, the first step is probably to address the low domestic onion productivity. The decline in agricultural productivity is foremost linked to the deterioration in soil fertility and organic matter (Patra *et al*., 2016). Increased use of soil fertilizers, therefore, is one of the ways to provide crops with essential nutrients to ensure optimal growth and development (Patra *et al*., 2016). Although intensive use of chemical fertilizers rather than organic fertilizers certainly and immediately increases yield, they also gradually deteriorate the soil physico-chemical properties in the long-term negating the concept of sustainable soil productivity (Patra *et al*., 2016). In addition, these fertilizers are increasingly becoming unaffordable to small producers with limited financial resources. Adoption of organic fertilizers (such as manure, compost, and vermicompost) to replace mineral fertilizers is needed to catalyze and sustain productivity.

Among organic fertilizers, vermicompost is well recognized for its beneficial effects as a soil amendment. Vermicompost is a low-cost organic amendment obtained from bio-oxidation process of organic substrates coupling synergistic actions of earthworms and microorganisms (Baghel *et al*., 2018). During vermicomposting, worms ingest organic substrates, grind them down in their digestive systems, and biochemically digest them before absorbing some of it in their body. The unabsorbed material is excreted as vermicastings and the vermicompost component is attributed to enhanced soil porosity, aeration, and soil aggregation. These castings also are rich in nitrogen, phosphorus, and potassium (NPK), micronutrients, and valuable soil microbes (Baghel *et al*., 2018). Research has shown that vermicompost improves soil bulk density, water holding capacity, pH, and electrical conductivity better than either conventional compost or raw material (Doan *et al*., 2015). Finally, the vermicomposting process not only usually results in a product with less bioavailable heavy metals than either the conventional compost or the raw material, but also in a product with more hormone like compounds, which are credited with accelerating plant growth resulting in shortened production cycles (Coulibaly *et al*., 2016).

The importance of vermicompost at increasing productivity of many crops has been well documented (Coulibaly *et al*., 2018; Tejada and Gonzalez 2006; Zaremanesh *et al*. 2017). Despite these monumental research strides in this field, little is known about the effect of vermicompost on onion productivity in West Africa. The specific objectives of this study were to investigate the efficacy of vermicompost on growth and yield of onion bulbs and to determine vermicompost application rates and timing for optimum productivity of onion bulbs (*Allium cepa*).

**Materials and methods**

*Survey area*

This study was conducted in Tchologo and Poro districts, which are the largest onion production districts in northern Côte d'Ivoire. One village was randomly chosen in each district for the study. Lassologo village was selected in Tchologo district, while Kombolokoura was selected in Poro district. Lassologo is located between latitudes 9°35 and 9°37 North and longitudes 5°11 and 5°50 West, whereas Kombolokoura is located between latitudes 8°26 and 10°27 North and longitudes 5°17 and 6°19 West.

The rainy season in both districts stretches from May to October and the dry season from November to April. Based on the meteorological records from a nearby weather station, the average temperature in Lassologo was 26.4°C and the total annual rainfall was 1260 mm. The average rainfall was 175 mm during the rainy season with a maximum of 263 mm in August. During the dry period, the average rainfall was 34 mm with 5 mm being the lowest in January. In Kombolokoura, the average annual temperature was 26.5°C and the total annual rainfall was 1286 mm. During the rainy season (May to October), the average rainfall was 182 mm with a maximum of 268 mm in August. The average rainfall during the dry season was 34 mm with a minimum of 5 mm in December and January. According to Dugué *et al*., (2007), the soil of Lassologo is sandy-clay when that of Kombolokoura is sandy-silty.

*Study material and resources*

North Côte d'Ivoire is also central to the production of cereal crops and cattle rearing in the country. The materials used for the experiment, therefore, consisted of cereal crops residues (maize stover and rice straw) and cattle manure (feces and urine). The crop residues were collected from different fields, while cattle manure was collected from the grazing pasture. The cattle manure was air-dried before its use in order to facilitate its handling and to reduce odor. Healthy adults of *Eudrilus eugeniae* weighing between 500 and 1200 mg were collected within the experiment area for the vermicomposting process. Purple of Galmi seeds, the variety of onion used in this study, were obtained from a commercial onion seeds company.

*Preparation of vermicompost*

The vermicompost was prepared during the dry season after the crops were harvested in December. Three pits each measuring 9 $m^3$ (3 m length x 3 m breadth x 1 m depth) were dug in each of the selected villages under a tree to limit wind and sunlight effects on the process. The crop residues were cut into 2-cm pieces. The bottom and the walls of each pit were wetted with water and 19.9 kg of wood ash was then sprayed on the bottom and walls to raise the pH and activate microbial activity (Bang-Andreasen *et al*., 2017). A 30-cm layer of maize stover were laid first followed by 30-cm layers of cattle manure, and rice straw. Each layer was watered with 200L and the pits were covered with palm leaves to maintain humidity. After 15 days of conditioning, the contents were manually turned over and watered to maintain 70–80% moisture content for another 15 days. After a total period of 30 days of conditioning, the contents were turned over again and the moisture adjusted to 70–80% to create favorable environment for earthworm's activity. One thousand eight hundred (1,800) matures individuals of *Eudrilus eugeniae* were introduced into each pit to initiate and drive the vermicomposting process (Coulibaly *et al*., 2011) for 3 months.

*Chemical characterization of substrates*

Before the start of the experiment, five samples of each type of soil, and the mature vermicompost were taken for chemical analysis. The samples were air dried in the shade and the pH, the total organic carbon (TOC), the total N, the total K, the total available P, the available calcium (Ca) and the available magnesium (Mg) were evaluated. The pH was measured using a pH-meter (Mettler Toledo S20) using 1:5 (w/v) suspension of substrate: distilled water. Total N was analyzed following the standard Kjeldhal method (Tandon, 1993). The nutrients P, K, Ca, and Mg were determined using ICP-AES after extraction of elements in $H_2O$ and 0.1N HCl solution. TOC was determined according to the method described by Walkley and Black (1934).

*Experimental design and Data Analysis*

Field plots planted with onion crop at a density of 36 plants $m^{-2}$ were set up at each of the two village experimental sites during three crop-growing seasons. The experiment design consisted of three randomized complete blocks. Each block contained 10 plots with a separation distance of 0.5 m. The blocks were separated each another by 1 m distance. Ten-treatments were evaluated in each block as follows:

-$T_0$: 0 t[vermicompost] $ha^{-1}$ (control plots)
-$T_1$: 10 t[vermicompost] $ha^{-1}$ before planting;
-$T'_1$: 5 t[vermicompost] $ha^{-1}$ before planting and at bulbing
-$T_2$: 20 t[vermicompost] $ha^{-1}$ before planting
-$T'_2$: 10 t[vermicompost] $ha^{-1}$ before planting and at bulbing
-$T_3$: 30 t[vermicompost] $ha^{-1}$ before planting
-$T'_3$: 15 t[vermicompost] $ha^{-1}$ before planting and at bulbing
-$T_4$: 40 t[vermicompost] $ha^{-1}$ before planting
-$T'_4$: 20 t[vermicompost] $ha^{-1}$ before planting and at bulbing
-$T_5$: 200 kg $ha^{-1}$ of NPK 20.10.10 before planting and 100kg $ha^{-1}$ of urea 46% at bulbing.

During the experiment, two groups of agronomic (growth) and harvesting parameters were evaluated. The growth parameters included the number of leaves per plant, the initial length of leaves, the length of leaves at bulbing, days to bulbing onset, the length of leaves at harvest, and the growth rate of leaves before and after bulbing were measured on 108 plants for each treatment. The parameters measured at harvest were bulb diameter, bulb length, bulb shape index, and yield. The bulb shape index (BSI) was computed as the ratio of bulb length to its diameter (equation 1). When BSI < 1, the bulb is referred to as flat; when BSI = 1, the bulb is said to be globular, while when BSI > 1, the bulb is denoted as Torpedro.

$$BSI=\frac{\text{Bulb Length}}{\text{Bulb Diameter}} \quad (1)$$

The response means, for each parameter, were analyzed by factorial analysis of variance (ANOVA) using SPSS package, Version 16 and presented by the mean and standard deviation (M ± SD). Least Significant Difference (LSD) multiple range-tests procedure were used to separate the means in each parameter category. Significant differences were determined at $P \leq 0.05$.

The interaction between organic fertilizer quantities, time and number of leaves in each type of soil was analyzed using the response surface methodology. A functional relationship (equation 2) of the number of leaves, the quantity of fertilizer and the time was established using the R software.

$$y=ax_1+ bx_2+c \quad (2)$$

Where: y = the total number of leaves, $x_1$ = the quantity of fertilizer, and $x_2$ = growth time.

## Results

*Soils and Vermicompost Characteristics*

The chemical characteristics of the soils at both research sites and the vermicompost produced and used in this study, summarized in Table 1, indicate significant variations between the soils as well as between soils and the vermicompost.

The pH, which varied from 5.1 to 7.1, were significantly different with the highest being in the vermicompost and the lowest in the sandy-silty soil.

The contents of C, N, and P in the soils and vermicompost, similarly were significantly different. The highest content of each element was in the vermicompost compared to both soils. The C:N ratio ranging from 18 to 80 and was significantly different from one media to the other. Vermicompost had the lowest C:N ratio (18±7) followed by the Sandy-silty soil (61±18) and the Sandy-clay soil (80±21) in that order. The contents of K, Ca, and Mg were also significantly lower in the soils than in the vermicompost.

**Table 1.** Initial chemical characteristics of the respective soils and the vermicompost. Ratio carbon azote (C:N), Carbon (C), Nitrogen (N), Phosphore (P), Potassium (K), Calcium (Ca), Magnesium (Mg).

| Media | pH, C:N ratio, and the concentrations of respective elements (mg kg$^{-1}$) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | pH | C:N | C | N | P | K | Ca | Mg |
| Sandy-clay soil | 5.9±0.2$^{b*}$ | 79.51±21.3$^{b}$ | 8110±327$^{b}$ | 102±32.67$^{b}$ | 2009±119$^{b}$ | 14.82±2.51$^{b}$ | 20.4±4.11$^{c}$ | 5.6±1.06$^{b}$ |
| Sandy-silty soil | 5.1±0.1$^{c}$ | 60.86±17.81$^{c}$ | 5600±592$^{c}$ | 92±29.61$^{b}$ | 500±84.3$^{c}$ | 17.55±3.04$^{b}$ | 39.7±5.24$^{b}$ | 6.84±1.42$^{b}$ |
| Vermicompost | 7.1±0.0$^{a}$ | 18.46±6.94$^{a}$ | 277000±1121$^{a}$ | 15000±717$^{a}$ | 8500±715.18$^{a}$ | 13500±989.77$^{a}$ | 11200±1001$^{a}$ | 5300±768.9$^{a}$ |

* Mean values denoted with the same letter in every column were not significantly different ($P > 0.05$).

*Effect of soil treatments on leaves number*

The number of leaves per plant as a function of time and treatment in both soils are presented in Table 2. The mean leaves number ranged from 2.45 to 2.95 in day 0 in both soils. However, there was no statistical difference in the onion seedlings leaves number supplied to the two soils during transplanting. The mean leaves number, 30 days after transplanting ranged between 5.80 and 6.37 in the sandy-clay soil and from 4.04 to 6.23 in the sandy-silty soil. Statistically, the leaves numbers were similar in both soils. In contrast to 30 days after transplanting, significant variations were observed in leaves numbers in both soils at 60, 90, and 120 days with respect to treatment. In the sandy-clay soil, the mean leaves number varied from 6.62 to 8.74 at 60 days and from 8.34 to 12.32 at 90 days.

At 60 and 90 days, leaves numbers were 8.18 and 12.32 for treatment $T_5$, 8.28 and 11.47 for $T_4$, which were higher than the others. At the harvest (120 days), the highest mean numbers of leaves per plant were observed in treatment $T_4$, $T'_4$, $T_5$ and $T_2$, while the lowest numbers of leaves were observed in $T_0$, $T'_1$, $T'_2$, $T_1$ and $T'_3$.

**Table 2.** Effect of soil treatments on the onion leaves number in the sandy-clay and sandy-silty soils.

| Treatment | Number of leaves per plant in the sandy-clay soil | | | | | Number of leaves per plant in the sandy-silty soil | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Day 0 | Day 30 | Day 60 | Day 90 | Day 120 | Day 0 | Day 30 | Day 60 | Day 90 | Day 120 |
| $T_0$ | 2.47 ± 0.26$^{a*}$ | 5.8 ± 1.67$^{a}$ | 6.62 ±1.32$^{b}$ | 8.34±2.65$^{c}$ | 8.89±2.72$^{b}$ | 2.66±0.11$^{a}$ | 4.04 ± 1,01$^{a}$ | 6.15±1.26$^{b}$ | 7.28 ±2.34$^{b}$ | 8.79 ±2.67$^{b}$ |
| $T_1$ | 2.45 ± 0.67$^{a}$ | 6,26 ± 1.16$^{a}$ | 7.38 ±1.2$^{ab}$ | 8.82±1.38$^{c}$ | 9.14±2.11$^{b}$ | 2.74±0.12$^{a}$ | 4.70 ± 0.57$^{a}$ | 6.76±1.34$^{b}$ | 8.78 ±2.42$^{ab}$ | 9.95 ±3.16$^{b}$ |
| $T_2$ | 2.52 ± 0.62$^{a}$ | 6.37 ± 1.05$^{a}$ | 8.08 ±2.4$^{a}$ | 11.36±2.76$^{ab}$ | 12.81±3.34$^{a}$ | 2.58±0.11$^{a}$ | 5.33 ± 0.95$^{a}$ | 8.49±2.12$^{ab}$ | 10.35 ±3.14$^{a}$ | 12.44 ±3.25$^{a}$ |
| $T_3$ | 2.45 ± 0.68$^{a}$ | 6.19 ± 1.56$^{a}$ | 7.58 ±2.14$^{ab}$ | 11.51±3.1$^{ab}$ | 12.98±2.62$^{a}$ | 2.61±0.31$^{a}$ | 5.02 ± 1.11$^{a}$ | 8.62±1.84$^{ab}$ | 9.23 ±3.04$^{ab}$ | 10.11 ±3.12$^{b}$ |
| $T_4$ | 2.57 ± 0.87$^{a}$ | 6.25 ± 2.12$^{a}$ | 8.28 ±1.84$^{a}$ | 11.47±2.82$^{ab}$ | 13.19±2.69$^{a}$ | 2.45±0.53$^{a}$ | 5.18 ± 0.86$^{a}$ | 8.96±1.67$^{ab}$ | 10.67 ±2.74$^{a}$ | 12.72 ±3.23$^{a}$ |
| $T'_1$ | 2.95 ± 0.86$^{a}$ | 5.88 ± 1.88$^{a}$ | 6.24 ±2.03$^{b}$ | 8.44±1.55$^{c}$ | 9.26±2.33$^{b}$ | 2.68±0.12$^{a}$ | 4.39 ± 0.67$^{a}$ | 6.18±1.42$^{b}$ | 7.85 ±2.11$^{b}$ | 9.06 ±3.15$^{b}$ |
| $T'_2$ | 2.46 ± 0.74$^{a}$ | 6.24 ± 2.15$^{a}$ | 6.53 ±2.11$^{b}$ | 9.13±1.95$^{bc}$ | 9.92±1.37$^{b}$ | 2.84±0.38$^{a}$ | 4.62 ± 0.67$^{a}$ | 7.82±2.14$^{b}$ | 8.62 ±2.22$^{ab}$ | 9.86 ±2.86$^{b}$ |
| $T'_3$ | 2.66 ± 0.75$^{a}$ | 6.04 ±1.44$^{a}$ | 7.56 ±1.53$^{ab}$ | 9.42±1.87$^{bc}$ | 10.33±2.48b | 2.64±0.27$^{a}$ | 5.84 ± 0. 55$^{a}$ | 7.3±1.37$^{b}$ | 9.14 ±2.3$^{ab}$ | 10.18 ±3.13$^{b}$ |
| $T'_4$ | 2.88 ± 0.45$^{a}$ | 6.28 ± 1.95$^{a}$ | 8.74 ±2.41$^{a}$ | 11.63±2.19$^{ab}$ | 13.73±2.36$^{a}$ | 2.36±0.11$^{a}$ | 5.15 ± 0.74$^{a}$ | 8.87±2.01$^{ab}$ | 10.63 ±3.06$^{a}$ | 12.96 ±3.17$^{a}$ |
| $T_5$ | 2.79 ± 0.67$^{a}$ | 6.23 ± 2.62$^{a}$ | 8.18 ±2.32$^{a}$ | 12.32±2.37$^{a}$ | 13.51±2.67$^{a}$ | 2.69±0.14$^{a}$ | 6.23 ± 2.62$^{a}$ | 9.14±2.38$^{a}$ | 10.28 ±2.69$^{a}$ | 12.67 ±3.06$^{a}$ |

† $T_0$ = 0 t ha$^{-1}$ of vermicompost (control plot), $T_1$ = 10 t ha$^{-1}$ of vermicompost before planting, $T'_1$ = 5 t ha$^{-1}$ of vermicompost before planting and at bulb start, $T_2$ = 20 t ha$^{-1}$ of vermicompost before planting, $T'_2$ = 10 t ha$^{-1}$ of vermicompost before planting and at bulb start, $T_3$ = 30 t ha$^{-1}$ of vermicompost before planting, $T'_3$ = 15 t ha$^{-1}$ of vermicompost before planting and at bulb start, $T_4$ = 40 t ha$^{-1}$ of vermicompost before planting, $T'_4$ = 20 t ha$^{-1}$ of vermicompost before planting and at bulb start, and $T_5$ = 200 kg ha$^{-1}$ of NPK 20.10.10 before planting and 100 kg ha$^{-1}$ of urea 46% at bulb start.

*Mean values denoted with the same letter in each column were not significantly different ($P > 0.05$).

The response surface analysis showed that in the sandy-clay soil, the number of leaves, the quantity of vermicompost applied a single time, and the growing time were strongly correlated ($r^2$=0.94). For vermicompost applied twice (before transplanting and at bulbing), the coefficient of determination was $r^2$ = 0.90. These coefficients indicate good fits of the model to the experimental data (Fig. 1**)**.

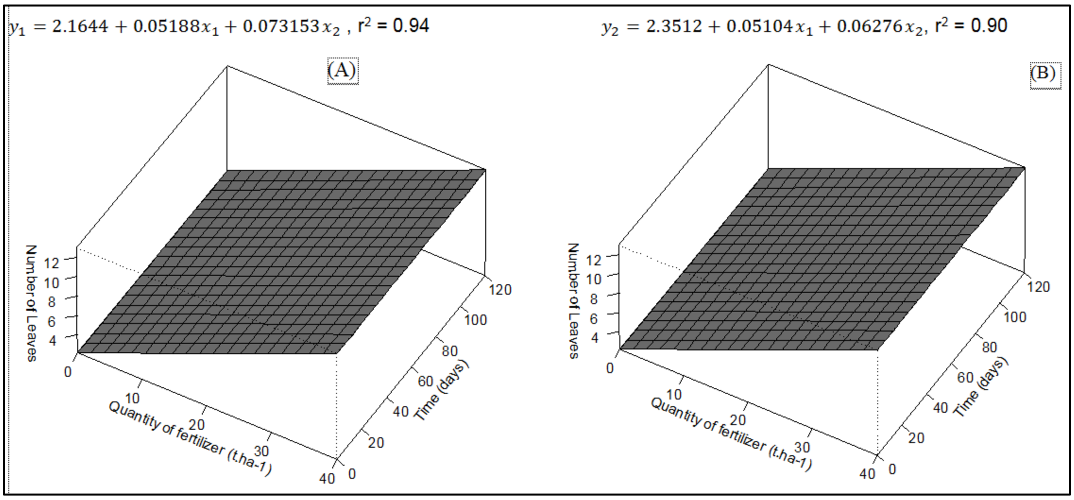


**Fig. 1.** Relationship between the number of leaves, the growing time, and vermicompost application rate: (A) single before transplanting and (B) two application before transplanting and at bulbing, in the sandy-clay soil.

The highest mean leaves number per plant in the sandy-silty soil, after 60 and 90 days from transplanting, were observed in treatment $T_5$ (9.14 at 60 days and 10.28 at 90 days) and the lowest in $T_0$ (6.15 at 60 days and 7.28 at 90 days). At harvest (120 days), the mean number of leaves per plant were higher in treatments $T_5$ (12.67), $T_4$ (12.72), and $T'_4$ (12.96) than in the other treatments. The lowest mean numbers of leaves per plant was obtained in $T_0$ (8.79), $T_1$ (9.95), $T'_1$ (9.06), and $T'_2$ (9.86). The relationships between the number of leaves, the quantity of fertilizer applied a single-time and two-time applications are shown in Fig. 2. The coefficients of determination were 0.93 for the one-time application and 0.90 for the two-times application, indicating good fits of both models.

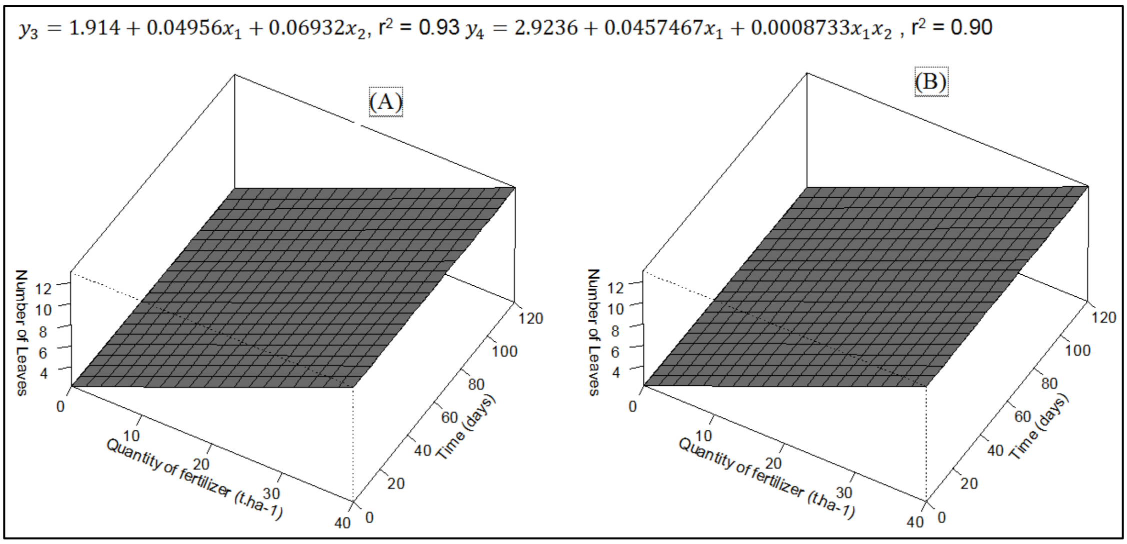


**Fig. 2.** Relationships between the number of leaves, the growing time, and vermicompost application rate: (A) one time before transplanting, and (B) two times before transplanting and at bulbing, in the sandy-silt soil.

*Effect of soil treatments on leaves length and bulb growth*

Table 3 summarizes the growth rate of onion leaves under each treatment in the sandy-clay soil, while Fig. 3 shows the respective growth profiles of leaves during the study period. The mean lengths of leaves at the time of transplanting were similar and ranged from 16.11 to 16.22 cm. Bulb formation started in the 4th week after transplanting for treatments $T_2$, $T_3$, $T_4$, $T_5$, $T'_3$ and $T'_4$, and in week 5 for treatments $T_0$, $T_1$, $T'_1$ and $T'_2$. Significant differences in the leaves' lengths were observed at this stage. The mean length of leaves, in descending order, were in treatments $T_5$ (40.63 cm), $T_4$ (37.53 cm), $T_3$ (36.3 cm), $T_2$ (35.17 cm), $T'_4$ (34.8 cm), $T'_2$ (33.23 cm), $T_1$ (32.2 cm), $T'_1$ (31.77 cm), $T'_3$ (31.5 cm) and $T_0$ (31.37 cm). No significant differences were observed in the leaves' length between treatments $T_5$, $T_4$ and $T_3$ or between treatments $T_2$, $T_3$, and $T_4$. Leaves length for treatments $T_0$, $T_1$, $T'_1$, $T'_2$ and $T'_3$ were also statistically not different.

**Table 3.** Growth parameters of onion leaves in the sandy-clay soil.

| Treatment | Initial length of leaves (cm) | Length of leaves at bulbing (cm) | Time to bulbing (wk.) | Growth rate pre-bulbing (cm wk.$^{-1}$) | Length of leaves at harvest (cm) | Growth rate post-bulbing (cm wk.$^{-1}$) |
|---|---|---|---|---|---|---|
| $T_0$ | 16.12±1.45$^{a*}$ | 31.37±3.74$^{e}$ | 5 | 2.55±1.56$^{c}$ | 35.4±4.15$^{c}$ | 0.37±0.11$^{d}$ |
| $T_1$ | 16.22±1.24$^{a}$ | 32.2±2.85$^{de}$ | 5 | 2.66±1.35$^{c}$ | 37.3±5.26$^{c}$ | 0.46±0.10$^{d}$ |
| $T_2$ | 16.16±1.62$^{a}$ | 35.17±2.12$^{bc}$ | 4 | 3.80±1.62$^{b}$ | 48.54±6.34$^{a}$ | 1.11±0.10$^{ab}$ |
| $T_3$ | 16.2±1.32$^{a}$ | 36.3±2.60$^{bc}$ | 4 | 4.02±1.03$^{ab}$ | 48.6±7.82$^{a}$ | 1.02±0.12$^{ab}$ |
| $T_4$ | 16.14±1.33$^{a}$ | 37.53±2.47$^{b}$ | 4 | 4.27±1.68$^{ab}$ | 50.1±8.06$^{a}$ | 1.04±0.11$^{ab}$ |
| $T_5$ | 16.18±1.41$^{a}$ | 40.63±2.38$^{a}$ | 4 | 4.89±1.84$^{a}$ | 50.88±7.95$^{a}$ | 0.85±0.10$^{c}$ |
| $T'_1$ | 16.13±1.37$^{a}$ | 31.77±1.69$^{e}$ | 5 | 2.61±0.67c | 36.41±6.72$^{c}$ | 0.42±0.11$^{d}$ |
| $T'_2$ | 16.13±1.64$^{a}$ | 33.23±3.01$^{c}$ | 5 | 2.85±1.31$^{c}$ | 37.19±6.37$^{c}$ | 0.36±0.10$^{d}$ |
| $T'_3$ | 16.15±1.22$^{a}$ | 31.5±2.55$^{e}$ | 4 | 3.07±1.43$^{bc}$ | 43.22±6.49$^{b}$ | 0.97±0.15$^{bc}$ |
| $T'_4$ | 16.11±1.25$^{a}$ | 34.8±2.34$^{cd}$ | 4 | 3.74±1.22$^{b}$ | 50.11±7.11$^{a}$ | 1.27±0.13$^{a}$ |

†$T_0$ = 0 t ha$^{-1}$ of vermicompost (control plot), $T_1$ = 10 t ha$^{-1}$ of vermicompost before planting, $T'_1$ = 5 t ha$^{-1}$ of vermicompost before planting and at bulb start, $T_2$ = 20 t ha$^{-1}$ of vermicompost before planting, $T'_2$ = 10 t ha$^{-1}$ of vermicompost before planting and at bulb start, $T_3$ = 30 t ha$^{-1}$ of vermicompost before planting, $T'_3$ = 15 t ha$^{-1}$ of vermicompost before planting and at bulb start, $T_4$ = 40 t ha$^{-1}$ of vermicompost before planting, $T'_4$ = 20 t ha$^{-1}$ of vermicompost before planting and at bulb start, and $T_5$ = 200 kg ha$^{-1}$ of NPK 20.10.10 before planting and 100 kg ha$^{-1}$ of urea 46% at bulb start.

*Values followed by same letters in a column are not significantly different ($P > 0.05$).

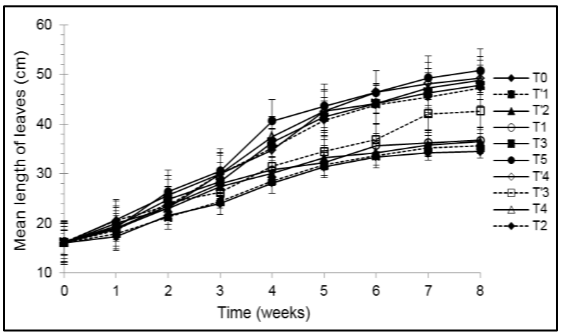


**Fig 3.** Growth of onion leaves in the sandy-clay soil as a function of soil treatments and growing time.

The mean growth rates from transplanting to bulbing varied from 2.55 to 4.89 cm wk.$^{-1}$. The highest growth rates of leaves were obtained with the treatments $T_5$ (4.89 cm), $T_4$ (4.27 cm), and $T_3$ (4.02 cm) and the lowest with $T_0$ (2.55 cm), $T_1$ (2.66 cm), $T'_1$ (2.61 cm), $T'_2$ (2.85 cm), and $T'_3$ (3.07 cm). The mean leaves growth rates declined post-bulbing, varying from 0.37 cm to 1.27 cm wk.$^{-1}$ The highest mean growth rates were observed in treatments $T'_4$ (1.27 cm), $T_4$ (1.04 cm), $T_3$ (1.02 cm), and $T_2$ (1.11 cm), while the lowest were observed in treatments $T_0$ (0.37 cm), $T_1$ (0.46 cm), $T'_1$ (0.42 cm), and $T'_2$ (0.36 cm).

In the sandy-silty soil, the mean values of onion growth parameters for various soil treatments are presented in Table 4. The initial mean lengths of leaves varied from 15.14 to 15.81 cm, which were not significantly different. However, significant differences in the length of leaves were observed between soil treatments. The longest leaves were observed in $T'_4$ (33.2 cm), $T'_3$ (33.76 cm), $T_4$ (33.42 cm), $T_3$ (33.45 cm), and $T_2$ (34.87 cm), whereas the shortest leaves were recorded in treatments $T_0$ (20.97 cm), and $T'_1$ (22.74 cm). Onion bulbs formation started in week 6 with all treatments. During the post-bulbing period, leaves lengths were significantly different between soil treatments. Except for treatments $T_0$ and $T'_1$, leaves growth rates were not significantly different between soil treatments (Fig. 4). Significant differences in leaves lengths were also measured amongst soil treatments at the harvest. The longest leaves were observed in treatments $T'_4$ (46.52 cm), $T_5$ (42.22 cm), $T_4$ (43.11 cm), $T_3$ (44.64 cm), and $T_2$ (43.19 cm), whereas the shortest leaves were recorded in the treatments $T_0$ (27.42 cm). Leaves growth rates, during this period, were statistically different, with the highest growth in treatments $T'_4$, $T'_2$, $T_5$ and $T_3$ and the lowest growth rates occurring in $T_0$, $T_1$, $T'_1$, and $T'_3$.

**Table 4.** Growth parameters of onion leaves in the sandy-silty soil.

| Treatment | Initial length of leaves (cm) | Length of leaves at bulbing (cm) | Time to bulbing (wk.) | Growth rate (cm wk.$^{-1}$) | Length of leaves at harvest (cm) | Growth rate post-bulbing (cm wk.$^{-1}$) |
|---|---|---|---|---|---|---|
| $T_0$ | 15.14±2.74$^{a*}$ | 20.97±4.35$^{c}$ | 6 | 0.97±0.23$^{b}$ | 27.42±5.36$^{e}$ | 0.58±0.01$^{e}$ |
| $T_1$ | 15.21±2.52$^{a}$ | 28.89±5.27$^{b}$ | 6 | 2.28±0.24$^{a}$ | 36.34±3.76$^{d}$ | 0.67±0.11$^{de}$ |
| $T_2$ | 15.31±3.25$^{a}$ | 34.87±4.39$^{a}$ | 6 | 3.26±1.14$^{a}$ | 43.19±5.13$^{ab}$ | 0.75±0.12$^{cd}$ |
| $T_3$ | 15.81±4.12$^{a}$ | 33.45±4.23$^{a}$ | 6 | 2.94±1.08$^{a}$ | 44.64±7.24$^{ab}$ | 1.02±0.10$^{ab}$ |
| $T_4$ | 15.22±3.32$^{a}$ | 33.42±4.74$^{a}$ | 6 | 3.03±1.24$^{a}$ | 43.11±2.34$^{ab}$ | 0.88±0.14$^{bc}$ |
| $T_5$ | 15.62±3.54$^{a}$ | 30.88±5.06$^{b}$ | 6 | 2.54±1.46$^{a}$ | 42.22±3.95$^{ab}$ | 1.03±0.11$^{ab}$ |
| $T'_1$ | 15.16±2.18$^{a}$ | 22.74±3.47$^{c}$ | 6 | 1.26±0.24$^{b}$ | 29.89±4.14e | 0.65±0.23$^{de}$ |
| $T'_2$ | 15. 4±3.45$^{a}$ | 29.31±5.29$^{b}$ | 6 | 2.34±0.37$^{a}$ | 39.73±6.06$^{cd}$ | 0.94±0.16$^{ab}$ |
| $T'_3$ | 15.34±3.47$^{a}$ | 33.76±3.51$^{a}$ | 6 | 3.07±0.86$^{a}$ | 40.38±8.17$^{bc}$ | 0.6±0.10$^{e}$ |
| $T'_4$ | 15.24±2.11$^{a}$ | 33.2±6.24$^{a}$ | 6 | 2.98±0.39$^{a}$ | 46.52±7.08$^{a}$ | 1.21±0.11$^{a}$ |

[†]$T_0$ = 0 t ha$^{-1}$ of vermicompost (control plot), $T_1$ = 10 t ha$^{-1}$ of vermicompost before planting, $T'_1$ = 5 t ha$^{-1}$ of vermicompost before planting and at bulb start, $T_2$ = 20 t ha$^{-1}$ of vermicompost before planting, $T'_2$ = 10 t ha$^{-1}$ of vermicompost before planting and at bulb start, $T_3$ = 30 t ha$^{-1}$ of vermicompost before planting, $T'_3$ = 15 t ha$^{-1}$ of vermicompost before planting and at bulb start, $T_4$ = 40 t ha$^{-1}$ of vermicompost before planting, $T'_4$ = 20 t ha$^{-1}$ of vermicompost before planting and at bulb start, and $T_5$ = 200 kg ha$^{-1}$ of NPK 20.10.10 before planting and 100 kg.ha$^{-1}$ of urea 46% at bulb start.

[*]Mean values designated with the same letter in every column were not significantly different ($\alpha$ = 0.05).

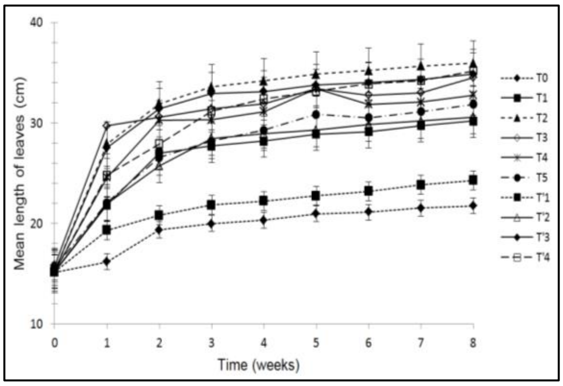


**Fig. 4.** Growth of onion leaves in the sandy-silty soil as a function of soil treatments and growing time.

*Effect of soil treatments on yield and yield attributes*

Onion yields and bulbs attributes at harvest are presented in Table 5. In the sandy-clay soil, the mean bulb-diameters were significantly different and ranged from 3.66 to 5.74 cm. The mean bulb shape index ranging between 0.76 and 0.95. Statistically, there was no significant difference between the indexes obtained with all the treatments. The mean onion yield ranged from 2.5 to 19.8 t ha$^{-1}$ with the highest yield being recorded when 20 t ha$^{-1}$ vermicompost was applied to the plots before planting, while the lowest yield was observed in the control plots. The onion yields, in decreasing order, in the sandy-clay soil were 19.8 t ha$^{-1}$>16.5 t ha$^{-1}$>15.5 t ha$^{-1}$≥ 15.2 t ha$^{-1}$>14.8 t ha$^{-1}$≥14.7 t ha$^{-1}$≥14.5 t ha$^{-1}$>12.7 t ha$^{-1}$≥12.5 t ha$^{-1}$>2.5 t ha$^{-1}$ for treatments $T_2$, $T'_4$, $T_3$, $T'_2$, $T'_3$, $T_4$, $T_5$, $T_1$, and $T_0$, respectively. On the sandy-silty soil, the mean onions bulb-diameter varied between 2.95 and 4.89 cm, while the mean bulb-length ranged from 2.83 to 3.74 cm. The smallest bulb-diameter and length were observed in $T_0$, $T_1$, $T'_1$, and $T'_2$ when the largest bulb-diameter and length were in $T_4$, $T_2$, $T_3$, $T_5$, $T'_3$, and $T'_4$.

Significant differences in onion yields amongst soil treatments were also observed on the sandy-silty soil. The lowest mean yield (1.5 t ha$^{-1}$) was obtained from control plots, while the highest mean yield (7.33 t ha$^{-1}$) was obtained from plots receiving 30 t [vermicompost] ha$^{-1}$ before planting. The mean onion yields, in decreasing order, was $T_3$ (7.3 t ha$^{-1}$) > $T'_3$ (5.7 t ha$^{-1}$) > $T_2$ (4.7 t ha$^{-1}$) ≥ $T'_4$ (4.7 t ha$^{-1}$) > $T_4$ (3.7 t ha$^{-1}$) ≥$T'_2$ (3.5 t ha$^{-1}$) > T1> (2.2 t ha$^{-1}$) $T'_1$ (1.8 t ha$^{-1}$) ≥ $T_0$ (1.5 t ha$^{-1}$).

**Table 5.** Effect of soil treatment and soil type on onion yield and onion bulbs attributes.

| Treatment | Yield and bulbs attributes in the sandy-clay soil | | | | Yield and bulbs attributes in the sandy-silty soil | | | |
|---|---|---|---|---|---|---|---|---|
| | Bulb diameter (cm) | Bulb length (cm) | Bulb shape Index | Yield (t. ha$^{-1}$) | Bulb diameter (cm) | Bulb length (cm) | Bulb shape Index | Yield (t. ha$^{-1}$) |
| $T_0$ | 3.66±0.84$^{b}$ | 3.07±0.42$^{b}$ | 0.84±0.1$^{ab}$ | 2.5±0.14$^{f}$ | 2.95±0.69$^{b}$ | 2.83±0.69$^{a}$ | 0.93±0.1$^{a}$ | 1.5±0.6$^{f}$ |
| $T_1$ | 4.23±0.56$^{ab}$ | 3.51±0.84$^{ab}$ | 0.82±0.2$^{ab}$ | 12.5±2.31$^{e}$ | 3.54±0.54$^{ab}$ | 3.21±0.84$^{a}$ | 0.9±0.1$^{ab}$ | 2.15±0.54$^{e}$ |
| $T_2$ | 5.54±1.02$^{a}$ | 4.47±0.71$^{ab}$ | 0.81±0.1$^{ab}$ | 19.8±3.14$^{a}$ | 4.37±1.11$^{a}$ | 3.43±0.76$^{a}$ | 0.78±0.1$^{ab}$ | 4.66±1.61$^{c}$ |
| $T_3$ | 5.64±0.89$^{a}$ | 4.71±1.12$^{a}$ | 0.83±0.1$^{ab}$ | 15.5±1.62$^{c}$ | 4.68±1.62$^{a}$ | 3.57±0.65$^{a}$ | 0.76±0.2$^{ab}$ | 7.33±1.34$^{a}$ |
| $T_4$ | 5.74±0.87$^{a}$ | 4.68±0.93$^{a}$ | 0.81±0.1$^{ab}$ | 14.71±3.27$^{d}$ | 4.89±0.96$^{a}$ | 3.74±1.2$^{a}$ | 0.76±0.1$^{b}$ | 3.66±1.22$^{d}$ |
| $T_5$ | 5.66±1.3$^{a}$ | 4.32±1.05$^{ab}$ | 0.76±0.1$^{b}$ | 12.7±1.68$^{e}$ | 4.67±1.63$^{a}$ | 3.43±1.26$^{a}$ | 0.73±0.1$^{b}$ | 4.33±1.05$^{c}$ |
| $T'_1$ | 4.02±1.11$^{ab}$ | 3.84±0.47$^{ab}$ | 0.92 ±0.1$^{ab}$ | 14.5±1.54$^{d}$ | 3.18±0.37$^{b}$ | 3.06±0.93$^{a}$ | 0.96±0.1$^{a}$ | 1.8±0.37$^{ef}$ |
| $T'_2$ | 4.32±0.74$^{ab}$ | 4.11±0.77$^{ab}$ | 0.95±0.1$^{a}$ | 15.25±1.85$^{c}$ | 3.47±0.94$^{b}$ | 3.21±0.87$^{a}$ | 0.92±0.1$^{a}$ | 3.5±0.97$^{d}$ |
| $T'_3$ | 5.18±1.21$^{ab}$ | 4.75±1.01$^{a}$ | 0.91±0.1$^{ab}$ | 14.75±2.21$^{d}$ | 4.23±1.32$^{a}$ | 3.11±1.18$^{a}$ | 0.74±0.1$^{b}$ | 5.66±1.12$^{b}$ |
| $T'_4$ | 5.51±1.34$^{a}$ | 4.37±0.92$^{ab}$ | 0.79±0.2$^{ab}$ | 16.47±1.93$^{b}$ | 4.84±1.41$^{a}$ | 3.62±0.95$^{a}$ | 0.75±0.1$^{b}$ | 4.66±1.23$^{c}$ |

* Mean values of parameters denoted with the same letter in each column were not significantly different (α = 0.05).

*Principal component analysis*

The principal component analysis (PCA) performed to further elucidate the relationships between the soil treatments and onion growth parameters in both soils are presented in Fig. 5. The PCA1 and PCA2, in sand-clay soil, explained approximately 73% and 21% of the total variances, respectively. In the Sandy-silty soil, PCA1 accounted for about 82% of responses, while PCA2 explained about 11% of the variation. The biplots enabled the evaluation of correlations of the quantified variables with lines in the same directions indicating closer correlations.

The number of leaves (Nl) and length of leaves (Ll) were highly correlated in both soils but the two parameters indicated little correlation to the onion yield (Yi). Yield attributes (the bulb diameter and bulb length) were highly correlated to the yield. In both soils, bulb shape index was weakly correlated to the onion plant growth parameters. The principal component analysis clustered the soil treatments into different groups based on their effect on plant growth parameters. In the sandy-clay soil, treatments $T_3$ and $T_2$ were highly correlated to the yield, while treatments $T_4$, $T_5$, and T'4 were strongly correlated to the number of leaves and the length of leaves. Treatments $T_1$, $T'_1$, $T'_2$, and $T'_3$ had similar effect on plant growth parameters. Treatment $T_0$, on the other hand, had no distinct effect on yield and was not correlated to the plant growth parameters. In sandy-silty soil, yield was strongly correlated with the treatments $T'_3$ and $T_3$, while both growth parameters were positively correlated with treatments $T_4$, $T'_4$, $T_2$, and $T_5$. Treatments $T_0$ and $T'_1$ had similar effects on plant growth parameters, whereas $T_2$ effects were different from that of all other treatments.

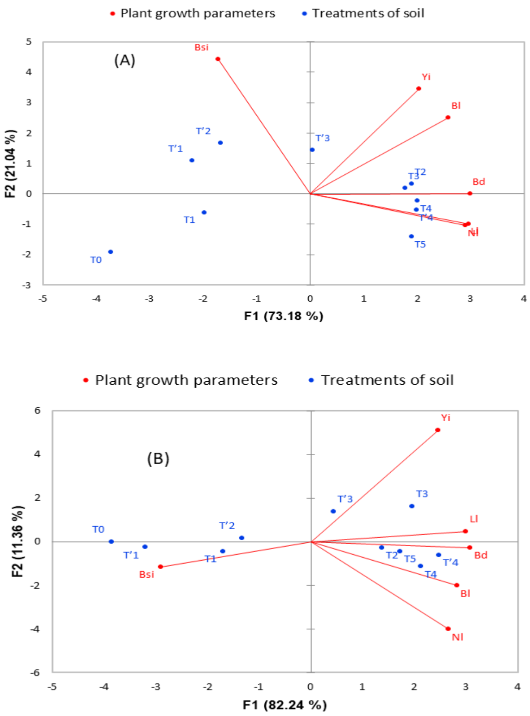


**Fig. 5.** Principal component analysis showing relationships between plant growth parameters and soil treatments: (A) sandy-clay soil and (B) sandy-silty soil.

## Discussion

*Characteristics of the substrates*

The pH of the both soils in this study was acid, while that of the vermicompost was close to the neutral. The acidic pH of both soils may be linked to accumulation of acidic compounds over the years. Farmers have in the past used inorganic fertilizers and pesticides to increase onion productivity. Such chemicals may result in accumulation of aluminum ions ($Al^{3+}$) and hydrogen ions (H+), which increase the acidity of the soils (Sradnick *et al*., 2013). The nearly neutral pH of vermicompost serves it well as a potential fertilizer (Ramnarain *et al*., 2019). The higher C:N ratio in both soils was an indication of their higher carbon but lower nitrogen contents compared to vermicompost as well as revealing their low fertility status. Research has shown that C:N ratios lower than 20 indicate advanced degree of organic matter stabilization and reflects satisfactory degree of fertility (Masmoudi *et al*., 2020). In the current study, the C:N ratios in both soils were higher than 20, while that of the vermicompost was approximately 18.

*Influence of the vermicompost on onion growth parameters*

During transplanting, the length of the leaves and the number of leaves per plant at both sites were statistically similar. This was certified that the plants selected for the study were homogeneous and healthy, and would thus reveal differences due vermicompost application rate and timing.

There were no significant differences in the number of leaves per plant 30 days after transplanting in both soils, which could be attributed to the slow nutrient release of the organic fertilizers. Although organic fertilizers show slow release of nutrients, they provide nutrients to plants for much longer durations.

The chemical fertilizer's slow-start, however, might have been due to the low soil-pH. Significant differences in leaves lengths, nonetheless, were observed after 30 days from transplanting. The differences in the number of leaves per plant between treatments $T_5$, $T_4$, $T'_3$, $T'_4$, $T_3$, $T_2$, and $T_1$ and treatments $T_0$, $T'_1$, and $T'_2$ could be linked to the fertilizer application rate. The first group of treatments might have released more nutrients for plant growth than treatments $T_0$, $T'_1$, and $T'_2$.

On the sandy-clay soil, bulbing started at week 4 and 5, while it started at week 6 on the sandy-silty soil. That difference could be explained by the initial characteristics of the soil pH. In this study, the sandy-silty soil was more acid than the sandy-clay soil. The soil pH is known to influence the mobility and the solubility of the plant nutrients. Nutrients might be more mobile and consequently easily available to the plants in the sandy-clay soil than in the sandy-silty soil. According to Sradnick *et al*., (2013), Ca, Mg, P, and K uptake by plants decreases with the drop of the soil pH. In fact, the action of pH on the physical, chemical and biological properties of the soil creates a more favorable environment for mineral nutrition and plant growth (Cayuela *et al*. 2006). Nutrient uptake by plants is better for pH near neutral (Cayuela *et al*. 2006; Xie *et al*., 2009). For example, in basic soils, phosphorus associates with calcium, whereas in acidic soils it combines with iron and becomes insoluble.

In both cases, it is unavailable for plants. On the other hand, at neutral pH, it is soluble and therefore easily assimilated by the plant. According to Raemaekers (2001), onion grows better in high fertile soil with pH between 6.2 and 6.8. In our experience, the pH of the sandy-silty soil was 5.1 and that of the sandy-clay soil was 5.9. This acidic pH thus may explain the low productivity in the control plots.

The difference between the controls, however, could be explained by the capacity of the sandy-clay soil in retaining more nutrients and facilitating their absorption by the plant. On the sandy-clay soil, there was a difference in the start of bulbing, which was a function of the treatments. That could be explained by the additional dose of nutrients provided in 4 weeks in the treatments $T_2$, $T_3$, $T_4$, $T_5$, $T'_3$, and $T'_4$ than the other treatments such as $T_0$, $T_1$, $T'_1$, and $T'_2$ that did it in 6 weeks. Brewster (1994) observed onion bulbing after 55 days in autumn and 43 days in spring. These differences in bulbing could be linked to the differences in soil characteristics, onion species, fertilizers used and the temperature at which the experience took place.

Results showed that, in general, for the same treatment, the growth rate of leaves before the bulb formation was higher than that after bulb appearance in each type of soil. This result could be explained by the principle of nutrients allocation. In this case, before the appearance of bulbs, all the nutrients were channeled to the leaves, which accelerated their growth, resulting in a high leaf growth rate. At the onset of bulb formation, the resources (nutrients) would henceforth be shared. One part would be for the growth of the leaves and the other part for the growth of the bulbs. As a result, a significant decrease in the growth rate of the leaves would be observed after the appearance of the bulbs. Previous research (Adjei-Twum, 1980), likewise observed that the growth rate of onion leaves before bulbing was significantly higher than that after bulbing.

The maximum number of leaves at the harvest was 13.73 in the sandy clay soil and 12.96 in the sandy silty soil. The maximum length was 50.88 cm in the sandy clay soil and 46.52 cm in the sandy-silty soil. Ikeda *et al.* (2019) found a variation of 13 to 15 in the number of leaves per onion plant. These differences might be due to the differences in the respective soils' fertility levels and the temperature.

*Effect of the vermicompost on yield and yield attributes*

The results of this study showed that the yield and its attributing parameters were higher with the vermicompost than with no fertilizer (control). In addition, the highest yields were obtained with the vermicompost compared to the inorganic fertilizer. These results were attributed to nutrient-value of the vermicompost and consequent change in the soil physico-chemical properties. According to Baghel *et al.* (2018), vermicompost creates favorable conditions for plant growth by improving soil porosity, aeration, producing water-stable aggregates and providing macronutrients and micronutrients to plants. The efficacy of the vermicompost is also linked to the earthworm's activities because during vermicomposting, greater mineralization of organic nutrients occurs in the digestive tract of earthworms, which increase minerals content in the vermicomposts (Ndegwa and Thompson 2001). In addition, earthworms secret growth hormones and enzymes that promote plant growth (Ndegwa and Thompson 2001). Assimilation of nitrogen by plants, which is also a function of soil treatment, have influences on agronomic health. In our study, the efficacy of the vermicompost compared to the inorganic fertilizer was associated with the initial physico-characteristics of the different soils. In fact, the acidic pH of the soils might cause the immobilization of many minerals such as Ca, P, Mg, etc. and therefore prevents their absorption by the plant. Another reason is that chemical fertilizers increases the ability of plants to absorb nutrients from the soil, implying that, over time the soil is left without mineral elements because of the excessive absorption in previous years. So, although chemical fertilizer is provided, the plant will no longer be able to find enough nutrients in the soil for growth and this negatively affect crop yield. Other researchers have reported that application of N beyond 84 kg $ha^{-1}$ decrease onion yield (Wiedenfeld 1994). In our study, the 200 $kg.ha^{-1}$ of NPK 20.10.10 applied before planting and the 100$kg.ha^{-1}$ of urea 46% applied at bulbing may explain the lower yield obtained with the inorganic fertilizer. In general, over application of NPK hinders growth and development of bulb (Wiedenfeld 1994). According to Tejada and Gonzalez (2006), vermicomposts utilization increased the yield of maize compared to a non-fertilized soil.

On the sandy-clay soil, the highest yield (19.8 $t.ha^{-1}$) was obtained with 20 $t.ha^{-1}$ of vermicompost applied before the transplanting. Above and below 20 $t.ha^{-1}$ application rate of vermicompost there was a decline in the yield. Similarly, on the sandy-silty soil, the highest onion yield was 7.33 $t.ha^{-1}$ and was obtained at 30 $t.ha^{-1}$ application rate of vermicompost spread before transplanting. This yield was 4.87 times, 1.57 times, 2 times and 1.69 times higher than those obtained, respectively, with either the: control, 20 $t.ha^{-1}$, or 40 $t.ha^{-1}$ of the vermicompost or inorganic fertilizer.

These results showed that, just like there is a limit on inorganic fertilizers application, there is a limit of vermicompost application rate. Up to that limit, the vermicompost can cause a decline in plant productivity. Furthermore, vermicompost is known to decrease mobility and leachability of certain micronutrients considered as heavy metals (Singh and Kalamdhad 2013). The negative charge surface might increase with the increase quantity of vermicompost spread. As a result, a lot of metal cations are retained on the vermicompost surface. The efficiency of the other elements like the macroelements becomes weak and that could be explained by the "Law of the minimum". The "Law of the Minimum" states that if one of the essential plant nutrients is deficient, plant growth will be poor even when all other essential nutrients are abundant.

In other words, the yield is proportional to the amount of the most limiting nutrient whichever nutrient it may be. Therefore, it is possible that the amounts of vermicompost higher than 20 $t.ha^{-1}$ and 30 $t.ha^{-1}$ in the sandy-clay and in the sandy-silty soil, respectively, retained more nutrients on their surface thus causing a deficiency of certain elements for the plant. In contrast, quantities lower than 20 $t.ha^{-1}$ and 30 $t.ha^{-1}$ of vermicompost in the sandy-clay soil and in the sandy-silty soil, respectively, did not probably introduce sufficient nutrients for plants growth. Onion yields were higher when 20 $t.ha^{-1}$ and 30 $t.ha^{-1}$ were applied one time before the transplanting in the sandy clay soil and in the sandy silty soil, respectively, than when they were applied twice (half before transplanting and the second part at bulbing). That foregoing indicated that vermicompost application before transplanting was more favorable or beneficial for onion productivity. Applying vermicompost before transplanting enables plants to uptake nutrients in time for their development. In contrast, when nutrients are applied in two steps (half before transplanting and half at bulbing), the first half may be insufficient for onion development, resulting in stressed plant or stunted plants due to mineral deficiencies. Fertilizer spreading followed by their incorporation into the soil during the growth of the plant, as onion producers often do, can stress the plant and therefore negatively affect the yield. Also, it appeared that for quantities up to 20 $t.ha^{-1}$ and 30 $t.ha^{-1}$ in the sandy-clay and the sandy-silty soil, respectively, the yields were lower when the vermicompost was spread one time before the transplanting than when it was spread two times (half before transplanting and the second part at bulb start).

That could be explained by the fact that above the optimum quantity of vermicompost, the micronutrients restrained in the different pores are higher when the vermicompost was brought one time. On the other hand, the number of nutrients retained is reduced when the vermicompost is spread in two steps. When bringing the vermicompost in a big quantity one time, the ability of negative charge surface of the vermicompost to retain micronutrients might be higher than when it is brought two times and consequently plants in the first case would have suffered from nutrients deficiencies than in the second case.

The differences in yields and in optimum quantities of vermicompost applied to obtain maximum yields, in this study, demonstrates that the efficacy of the vermicompost were a function of soil-type and the initial characteristics of the soil. The highest yield registered on the sandy-clay soil could be explained by the fact that onion production requires a sandy-clay soil and not a sandy-silty soil. Moreover, onions in this study were all flat. That indicates that the sandy-clay and the sandy-silty soils might be favorable to the flat shape bulbs. These types of soils might permit the growth of the bulbs in the larger sense than that in the length. However, flat onions are more desired than globular and torpedro onions.

*Principal component analysis*

The high positive correlation between leaves and yield is probably based on the role leaves play in the plant nutrition. Leaves capture sunlight and carbon dioxide which drive photosynthesis necessary for plant growth, maintenance, and yield. The increase in onion-bulbs yield with increase in the number of leaves can thus be associated with enhanced photosynthesis, improved nutrients assimilation, and a concomitant increase of food reserve accumulation in the bulbs. Similarly, Mettananda and Fordham (1999) noted that, the number of leaves and leaf area positively impact onion (*Allium cepa*) production. Giri *et al.* (2018), who also documented a positive correlation between leaves number and bulb yield of Lilium hybrid cv. Sorbonne, attributed this observation to the ability of leaves to accumulate calcium for bulb. The strong correlation between the number of leaves and the leaf length, on the other hand, was expected given that both attributes are components of the same organ. Rahman *et al.* (2015) found a high correlation between onion leaves number and leaf length in a nutrients-deficient soil. The weak correlations between the bulb shape index to: the yield, the bulb length, the bulb diameter, the number of leaves, and leaves length might be attributed to bulb shape index being governed by a gene different from the one that governs the other parameters. Pavlović *et al.*, (2016) working with different genotypes of onion, similarly, did not find any correlation between bulb shape index and yield.

## Conclusion

Results from this study revealed that the efficacy of vermicompost is dependent on soil type, application rate, and timing. Vermicompost was more effective at improving onion yield on a sandy-clay soil than on a sandy-silty. Optimum production of onion in the sandy-clay soil was achieved at the application rate of 20 t $ha^{-1}$ of vermicompost before transplanting. Vermicompost application above 20 t $ha^{-1}$ decreased onion productivity demonstrating that over-application of organic vermicompost has similar adverse effect, on productivity, as application of excess inorganic fertilizers.

## Conflict of interest

The authors declare that they have no conflict of interest.

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## References

**Adjei-Twum DC.** 1980. The influence of bulb size and bulb cutting on the growth and yield of shallots (*Allium cepa* var. *Aggregatum* G. Don.) in Ghana. Journal of Horticultural Science **55,** 139-143.

**Baghel B, Sahu R, Pandey D.** 2018. Vermicomposting an economical enterprise for nutrient and waste management for rural agriculture. International Journal of Current Microbiology and Applied Sciences **7,** 3754-3758.

**Bang-Andreasen T, Nielsen JT, Voriskova J, Heise J, Rønn R, Kjøller R, Hansen HCB, Carsten S, Jacobsen CS.** 2017. Wood ash induced pH changes strongly affect soil bacterial numbers and community composition. Frontiers in Microbiology **8,** 1-14.

**Cayuela ML, Sanchez-Monedero MA, Roig A.** 2006. Evaluation of two different aeration systems for composting two-phase olive mill wastes. Process Biochemistry **41,** 616-623

**Coulibaly SS, Edoukou FE, Kouassi KI, Barsan N, Nedeff V, Zoro Bi IA.** 2018. Vermicompost utilization: A way to food security in rural area. Heliyon **4,** e01104

**Coulibaly SS, Kouassi KI, Tondoh EJ, Zoro Bi IA.** 2011. Impact of the population size of the earthworm *Eudrilus eugeniae* (Kinberg) on the stabilization of animal wastes during vermicomposting. Philippine Journal Agricultural Scientist **94,** 88-95.

**Coulibaly SS, Tondoh EJ, Kouassi KI, Barsan N, Nedeff V, Zoro Bi I A.** 2016. Vermicomposts improve yields and seeds quality of *Lagenaria siceraria* in Côte d'Ivoire. International Journal of Agronomy and Agricultural Research **8,** 26-37.

**Doan TT, Henry-des-Tureaux T, Rumpel C, Janeau JL, Jouquet P.** 2015. Impact of compost, vermicompost and biochar on soil fertility, maize yield and soil erosion in Northern Vietnam: A three-year mesocosm experiment. Science of Total Environment **514,** 147-154.

**Dugué P, Koné FR, Koné G.** 2007. Gestion des ressources naturelles et évolution des systèmes de production agricoles des savanes de Côte d'Ivoire : conséquences pour l'élaboration des politiques agricoles. Hal Cirad - Prasac. 12 p.

**Giri TK, Beura S, Acharjee S, Palai SK.** 2018. Impact of various nutrients on flowering and bulb production of oriental *Lilium hybrid* cv. Sorbonne. The Pharma Innovation Journal **7,** 103-106.

**Hossain M, Ahmed M, Ehsanul HM, Shefat AM, Nabi NM.** 2017. Quality Seed of Onion: Effect of Micro and Macronutrients. Annual Research and Review in Biology **20**, 1-11.

**Ikeda H, Kinoshita T, Yamamoto T, Yamasaki A.** 2019. Sowing time and temperature influence bulb development in spring-sown onion (*Allium cepa* L.). Scientia Horticulturae **244,** 242-248.

**Liguori L, Califano R, Albanese D, Raimo F, Crescitelli A, Matteo MD.** 2017. Chemical composition and antioxidant properties of five white onion (Allium cepa L) landraces. Journal of Food Quality **1,** 1-9.

Masmoudi **S,** Magdich **S,** Rigane **H,** Medhioub **K,** Rebai **A,** Ammar **E.** 020. Effects of compost and manure application rate on the soil physico-chemical layers properties and plant productivity. Waste Biomass and Valorization **11,** 1883-1894.

**Mettananda KA, Fordham R.** 1999. The effects of plant size and leaf number on the bulbing of tropical short-day onion cultivars (*Allium cepa* L.) under controlled environments in the United Kingdom and tropical field conditions in Sri Lanka. Journal of Horticultural Science and Biotechnology **74,** 622-631.

**Ndegwa PM, Thompson SA,** 2001. Integrating composting and vermicomposting of the treatment and bioconversion of biosolids. Bioresource Technology **76,** 107-112.

**Nicastro HL, Ross SA, John A, Milner JA, 2016.** Garlic and onions: Their cancer prevention properties. Cancer Prevention Research **8,** 81-189.

**Patra S, Mishra P, Mahapatra SC, Mithun SK. 2016.** Modelling impacts of chemical fertilizer on agricultural production: a case study on Hooghly district, West Bengal, India. Model. Earth Systems and Environment **2,** 1-11.

**Pavlović N, Zdravković M, Gvozdanović-Varga J, Mladenović J, Pavlovic R, Zdravković J. 2016.** Heritability mode of onion (*Allium cepa* L.) bulb shape index. Ratarstvo i Povrtarstvo **53,** 85-89.

**Raemaekers RH.** 2001. Crop production in tropical Africa. Directorate General for International Cooperation (DGIC), Brussels, Belgium. 1540 p.

**Rahman IU, Afzal A, Iqbal Z, Ijaz F, Khan S, Khan SA, Shah A, Khan K, Niaz Z, Ali N.** 2015. Influence of foliar nutrients application on growth and yield of onion grown in nutrient deficient soil. Bangladesh Journal of Botany **44,** 613-619.

**Ramnarain YI, Ansari AA, Ori L.** 2019. Vermicomposting of different organic materials using the epigeic earthworm Eisenia foetida. International Journal of Recycling of Organic Waste in Agriculture **8,** 23-36.

**RONGEAD, CHIGATA.** 2015. Diagnostique de la filière oignon en Côte d'Ivoire, 34 p.

**Singh J, Kalamdhad AS.** 2013. Reduction of bioavailability and leachability of heavy metals during vermicomposting of water hyacinth. Environmental Science and Pollution Research **20,** 8974-8985.

**Sradnick A, Murugan R, Oltmanns M, Raupp J, Joergensen RG.** 2013. Changes in functional diversity of the soil microbial community in a heterogeneous sandy soil after long-term fertilization with cattle manure and mineral fertilizer. Applied Soil Ecology **63,** 23-28.

**Tandon HKS.** 1993. Method of analysis of soils, plant, water and fertilizer. New Delhi, Fertilizer Development and Consultation Organization, 143 p.

**Tejada M, Gonzalez JL.** 2006. Effect of foliar application of beet vinasse on maize yield. Biological Agriculture and Horticulture **24,** 197-214.

**Walkley AG, Black IA.** 1934. An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science **37,** 29-37.

**Wiedenfeld R.** 1994. Nitrogen rate and timing effects on onion growth and nutrient uptake in a subtropical climate. Subtropical Plant Science **46,** 32-37.

**Xie W, Zhou J, Wangb H, Chen X, Lu Z, Yu J, Chen X.** 2009. Short-term effects of copper, cadmium and cypermethrin on dehydrogenase activity and microbial functional diversity in soils after long-term mineral or organic fertilization. Agriculture, Ecosystems & Environment **129,** 450-456.

**Zaremanesh H, Nasiri B, Amiri A.** 2017. The effect of vermicompost biological fertilizer on corn yield. Journal of Materials and Environmental Science **8,** 154-159.