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Differential Responses of *Allium sativum. (L)* (Alliaceae) to Compost Application and Mycorrhizal Inoculation Under Field Conditions

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Abstract: Although the dependency of garlic to arbuscular mycorrhiza fungi (AMF) has been proven in pot experiment with an appropriate 2/3 compost/soil ratio, whether this performance can also be successful under field conditions is yet to be investigated on growth and yield attributes of the crop. The experimental design was a randomized complete block comprising six treatments replicated four times each, where the main treatment 2/3 (compost/soil) ratio +30 g AMF was compared to 1/3 (compost/soil) ratio +30 g AMF, with or without NPK-fertilizer. How different fertilizer receipts affected the Allium sativum growth and yield parameters, as well as the post-harvest soil physico-chemical properties was assessed and compared. The growth and productivity of garlic positively responded and in repeated cropping campaigns to the integrated application of 2/3 ratio (compost/soil) inoculated with 30g mycorrhiza. Additional application of 5g NPK-fertilizer to compost-soil-mycorrhiza mix was detrimental to garlic growth, because of excess nutrients that hampered the garlic-plant mycorrhization frequency and intensity. Whereas organic treatment increased the soil pH from 6.07 prior to cultivation to 6.8 at post-harvest, the soil Mg, Ca and phosphate contents were instead reduced in post-harvest soil following assimilation by the host plant, while the organic matter content was significantly enhanced due to improved soil fertility by compost. For a sustainable production of garlic in the field, application of 2/3 ratio (compost/soil) inoculated with 30g mycorrhiza within the host-plant rhizosphere, and without NPK-fertilizer is highly suggested to enrich the soil in nutrients and organic matters.

Keywords: *Allium sativum, compost, compost/soil ratio, mycorrhiza, growth, Yield*

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1. Introduction

If plant nutrition and health are to be improved, the utilization of chemical inputs and pesticides need to be lower, to cope with the new paradigm in agriculture that is being focused on soil beneficial microorganisms [1]. Arbuscular mycorrhizal fungi (AMF), a vital functional group of beneficial soil fungi that has been reported to form a mutualistic symbiosis with roots in 80% of plant species are receiving increased global attention [2]. According to Gianinazzi *et al.*[3], AMF provides diverse ecosystem services, including enhanced water uptake, or increased plant tolerance to biotic and abiotic stresses, thus contributing to restriction of agrochemical usages [4,5]. Similarly, organic fertilizers are gaining special reputation in sustainable agriculture [6,7,8], through improved soil physico-chemical properties [9]. Organic compost substrates such as farm yard, poultry and green manures do not only provide the organic matters, but also increase the degree of soil fertility [10], or organic acids that help in dissolving soil nutrients and make them available to plants [11]. Garlic (*Allium sativum L.*) is a plant particularly valued and cultivated in tropical regions, where it is widely recognized as a precious spice and a popular medicine against various physiological disorders [12]. In Cameroon, garlic is cultivated mainly in the north-west, north and far-north regions, but its productivity remains low, ranging from 8.8-2.76 t/ha [13]. This production that barely reaches 50% of the national demand, is regularly competed by importations of Chinese garlic, because of two main constraints that include low soil fertility and climate variability [13]. Previous investigations have revealed positive effects of biofertilizers on garlic growth and yield in pots through application of compost-mycorrhiza at1:3 or 2:3 ratios [14], or increased garlic production in the field after bio and organic fertilizer application [15]. In the present research we provided garlic plants at sowing with biological fertilizers (compost/soil in the ratios 1:3 or 2:3; mycorrhiza) prior to assessment of their impact on the plant growth and yield attributes in the field.

2. Material and Methods

Study sites: The study was conducted at Dang, in the Adamawa Region of Cameroon during 2020-2021 and 2021-2022 cropping seasons. The region that belongs to the Guinean Savannah high-altitude agro-ecological zone is located between the 6th-8th degrees North latitude, the 11th-15th degree East longitude, and covers averagely 62000 km^2. The climate is of Sudano-Guinean type, characterized by unimodal rainfall distribution with 20°C average temperature, while the relative humidity remains high from April to October. Soils are classified as red ferrallitic developed on old basals, whereas the vegetation is represented by ornamental, edged, native savannah and gallery forests plants [16].

Plant material and fertilizers

Mature garlic (*Allium sativum*) bulbs with pink cloves were purchased in a phytosanitary store in Ngaoundere town. The organic amendment used during this study was a compost produced from cows dungs as substrate, following the composting method described by Ngakou *et al.* [17]. Mycorrhiza as biological fertilizer was a mixture of sieved soil-sand, rice root fragments and the fungi of the genera *Glomus* and *Gigaspora* at 150 spores/g of substrate, produced in the microbiology laboratory of the Institute of Agricultural Research for Development (IRAD) Ngaoundere. The inorganic fertilizer (NPK: 20:10:10) as positive control was the widely used by garlic growers in the region.

Experimental design, units and treatments

Field trials were conducted on 176 m² surface area during 2021 and 2022 crop campaigns. The study sites were fenced with *Tithonia diversifolia* stems to protect plants from devastating effect of cattle, usually abandoned to feed in natural environment in the region. The soil was cleared and ploughed with hoes at 5 cm depth. The experimental set up was a Randomized Complete Block (RCB) design comprising 6 treatments, each of which was replicated four times on each block. Treatments consisted of a positive control with NPK: (20:10:10) (NPK), a negative control without any of the fertilizer (NC), a compost-soil mixture in the 2:3 ratio with 30g Mycorrhiza (C/S(2:3)+AMF); a compost-soil mixture in the 1:3 ratio with 30g Mycorrhiza (C/S(1:3)+AMF); a compost-soil mixture in the 2:3 ratio with 30g Mycorrhiza with 5g NPK (C/S(2:3)+AMF+NPK); a compost-soil mixture in the 1:3 ratio with 30g Mycorrhiza with 5g NPK (C/S(1:3)+AMF+NPK). For the 1:3 ratio compost-soil mixture, 500g compost and 500g of soil were used, while for the 2:3 ratio, 1000g of compost and 1500g of soil were used instead. NPK (20:10:10) was applied at 64 days after sowing.

Garlic cloves were sown directly without pre-treatment in the field. The seedling holes were 3 cm depth in which a single clove was sown by placing the growing site pointing the soil surface. Experimental plots (EP) were 1m apart, each of which consisted of 20 plants arranged on 5 rows of 4 plants each. Plants were 15 cm apart separated each other on a line, and 25cm between lines (Figure 1). Parameters were assessed on all the twenty plants, after every 14 days after sowing (DAS) from the 42nd to the 84th DAS.

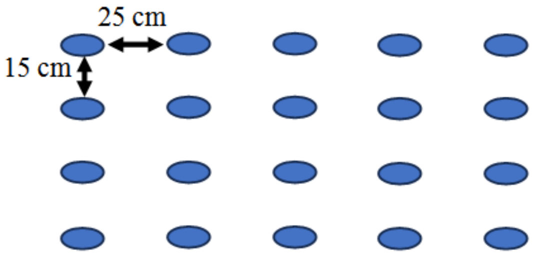


Figure 1. Experimental plot showing plant density

Determination of the soil physico-chemical properties

Conventional analyses were conducted at the Ngaoundere Institute of Technology and Engineering Laboratory to determine the physico-chemical contents of soil. Soil pH and electrical conductivity were determined in a 1:1 (v/w) water-bulk soil suspension using respectively a 0.001 precision pH meter (Matest, Treviolo, Italy) and a conductivity meter (Bibby Scientific, Bibby Scientific, Staffordshire, UK), according to AFNOR [18]. The other main soil parameters such as organic matter, organic carbon, mineral content, ash and water content were determined using described methods approved by Youseef *et al.* [19]. The determination of the soil's organic carbon content was the first step toward indirectly determining the amount of organic matter. Sampled soils were first air dried at 72°C and crushed to pass through a 0.5-2 mm sieve. The available phosphate (P) was extracted and then analyzed using the molybdate blue method described by Murphy and Riley [20]. Exchangeable cations (Ca and Mg) were extracted using ammonium acetate and cations were determined by atomic absorption spectroscopy using the absorption spectrophotometer [21].

Assessment of plant growth and yields parameters

Emergence seeds rate: The emergence rate was assessed at 21 days after sowing using the following formula: **Emergence rate = emerged seeds/sown seeds.** The morphological characteristics of plants such as the number of leaves per plant, plant height, stem diameters were evaluated at 56, 70 and 84 days after sowing (DAS) on 80 plants per treatment (20 plants per replicate), respectively by counting the number of leaves per plants, or measuring the plant height and the stem diameter using a graduated ruler (cm) and a slide caliper. The yield was assessed by evaluating from 80 bulbs per treatment, the bulb diameter using a slide caliper, the number of cloves per bulb by separating and counting the cloves per bulbs, or measuring the bulb weight using a Sartorius balance at 0.001 g sensibility. The total bulb yield in an hectare using the following formula: BYld = (AvYld/Plt/Treat) x 150.000 [22], where 150.000 is the theoretical number of plants per hectare, AvYld/Plt/Treat is the bulb weight per plant (Kg) and per treatment.

Determination of the mycorrhizal colonization

indexes: To assess the mycorrhization rate in plants, *Allium sativum* roots were first carefully washed, and young ones were selected and cut into 1-2 cm length; they were then put in test tubes containing 10 % potash, and heated in water bath at 90 °C for 30 min to destroy the plant cells content and decolorize tannins in woody roots; potash was thrown out, then root solution was filtered and rinsed with acidified water to neutralize it; *Allium sativum* roots were incubated in the cotton blue reagent within the water bath for 10 to 15 minutes. The solution was again filtered and rinsed with distilled water before roots were mounted on the slide in a drop of water for direct observation under the microscope [23].

The estimated parameters for mycorrhization state were evaluated as requested by Sghir *et al.* *[24]*. The frequency of mycorrhization F(%) was used to assess the percentage of host plant colonization by arbuscular fungi as:

F(%) = 100 X(N-N0)/N, where, **N** is number of fragments observed; **N0**, the number of non-mycorrhizal fragments.

The intensity of mycorrhization (I%) was evaluated by assigning each root fragment (a sample of 100 fragments) a class score from between 0 and 5, based on the estimate of the proportion of the colonized root cortex by AMF as follows: 0 = no infection; 1 = trace; 2 = less than 10%; 3 = 10-50%; 4 = 51 to 90%.

I% = (95n5-70n4-30n 3 - 5n2 n1)/N, where n5, n4, n3, n2 and n1 are the number of root fragments rated from 1 to 5 [24].

3. Results and Discussion

Physico-chemical properties of soil before sowing and after harvest

The physico-chemical properties of soils differed between samples before campaign (BC) and after campaign (AC) as indicated in Table 1. Treatments significantly contributed to increasing soil pH in AC samples, respectively during the 2021 ($p = 0.0027$) and 2022 ($p=0.0046$) campaigns, as compare to soil pH sampled before BC. The hydroxyl group contained in compost has been reported as the main factor involed in the raising of soil pH [25]. Compost has also been involved in increased soil pH through exchangeable bases (Ca, Mg, K, and Na) and the argilo-humic complexes [26]. However, pH ranged from 6.07 to 6.27 in the first year and from 6.4 to 6.8 in the second year, indicating that acidic soils are favorable for growth and development of *Allium sativum* plants. This result confirms those of Sethi *et al.* [27], who reported good growth of *Allium sativum* plant at the ideal soil pH range between 6 and 7. Whereas, Mg and phosphates were significantly reduced in the post-harvest soil for the two cropping campaigns, Ca was significantly reduced only in soil AC during the second cropping campaign. The soils Mg and phosphate were instead less elevated in post-harvest than in prior cultivated soils ($p<0.0001$), confirming the fact that this mineral has been assimilated by the plant for its growth and development. These results line with those of Yoni *et al.* [28], who pointed out decreased mineral substances (nitrogen, phosphorus and others) in the dry tropics soils after cultivation. The organic matter content was significantly enhanced ($0.005 < p < 0.029$) in post-harvest soils, attributed to improved soil fertility due to applied of such an organic fertilizer as compost [29]. According to Biaou *et al.* [30], application of compost at the rate of 30 t/ha improves the soil chemical properties after crop harvest.

The number of emerged seedlings per treatment gradually increased from 14-42 DAS during the two cropping campaigns (Table 2). At 14 DAS of the first year, the number of emerged seedlings from treatment C/S (1:3)+Myc NPK was significantly more elevated ($p = 0.0014$) than that of any other treatment. At 28 DAS, treatments C/S(2:3)+Myc, C/S(1:3)+Myc+NPK, C/S(1:3)+Myc and C/S(2:3)+Myc+NPK showed significant increase in the emergence rate of seedlings compared to those of treatments NC and NPK, the best emergence rate accounting for treatments C/S(2:3)+Myc and C/S(1:3)+ Myc+NPK at 28 DAP ($p = 0.0001$) and 42 DAS ($p = 0.011$).

Table 1. Some physico-chemical properties of the experimental soils before and after cultivation

Parameters	Cropping period	2021 campaign	2022 campaign
pH	BC	6.07 ± 0.045^{a} 6.27 ± 0.025^{b}	6.40 ± 0.09^{a}
	AC		6.8 ± 0.07^{b}
	p-value	**0.0027**	**0.0046**
EC (us/cm)	BC	16.54 ± 0.20^{a}	25.60 ± 1.17^{a}
	AC	65.46 ± 0.57^{b}	99.37 ± 0.89^{b}
	p-value	**0.0001**	**0.0001**
OM (g/100g DM)	BC	19.65 ± 1.13^{a}	14.14 ± 0.16^{a}
	AC	25.04 ± 11.18^{b}	14.72 ± 0.25^{b}
	p-value	**0.0047**	**0.0299**
Phosphates (mg/kg DM)	BC	22.71 ± 10.29^{b}	12.44 ± 6.12^{b}
	AC	12.08 ± 0.11^{a}	12.08 ± 0.11^{a}
	p-value	**0.1483**	**0.0001**
Ca (mg/100g DM)	BC	216.24 ± 16.32^{a}	349.46 ± 30.96^{b}
	AC	216.24 ± 16.32^{a}	224.05 ± 27.72^{a}
	p-value	**0.8492**	**0.0064**
Mg (mg/kg DM)	BC	346.8 ± 20^{b}	336.83 ± 26.66^{b}
	AC	162.2 ± 0^{a}	$132.6\pm0.6\pm^{a}$
	p-value	**0.0001**	**0.0002**

BC: before cropping campaign; AC: After cropping campaign;

Influence of compost and mycorrhiza on *Allium sativum* shoots emergency at between 14-42 days after sowing (DAS)

Table 2. Emergence rate of *A. sativum* plants (%) as affected by different receipts over time (DAS) and cropping campaigns

	Germination rate (%) 2021 cropping campaign			Germination rate (%) 2022 cropping campaign		
Treatments	**14 DAS**	**28 DAS**	**42 DAS**	**14 DAS**	**28 DAS**	**42 DAS**
NPK	40.47 a	51.19 a	97 a	56.54 a	91.66 ab	97,61a
CN	43.45 a	58.92 ab	97.02 a	63.09 ab	88.69 a	99.40 ab
C/S (2:3)Myc	39.48 a	72.61 e	103.57 b	70.23 b	89.88 ab	100.85b
C/S (1:3) Myco	47.61 a	66.07 d	101.19 b	60.71 ab	91.83 ab	100.02 b
C/S (2:3) Myc NPK	43.45 a	62.5 c	103.57 b	66.07 ab	95.83 b	100.8 b
C/S (1:3) Myc NPK	63.09 b	72.61 e	105.35 b	70.83 b	95.23 ab	100 b
P-value	0.0014	0.0001	0.0110	0.114	0.219	0.175

DAS = Days After Sowing; NPK: positive control with NPK: (20:10:10); NC: negative control without any of the fertilizer; C/S-2:3+AMF: compost-soil mixture in the 2:3 ratio with 30g Mycorrhiza; C/S-1:3+AMF: compost-soil mixture in the 1:3 ratio with 30g Mycorrhiza; C/S(2 :3)+AMF+NPK: soil-compost mixture in the 2:3 ratio with 30g Mycorrhiza and 5g NPK; C/S-1:3+AMF+NPK: soil-compost mixture in the 1:3 ratio with 30g Mycorrhiza and 5g NPK. For a given parameter, values affected with the same letter are not significantly different between treatments at the indicated probability threshold.

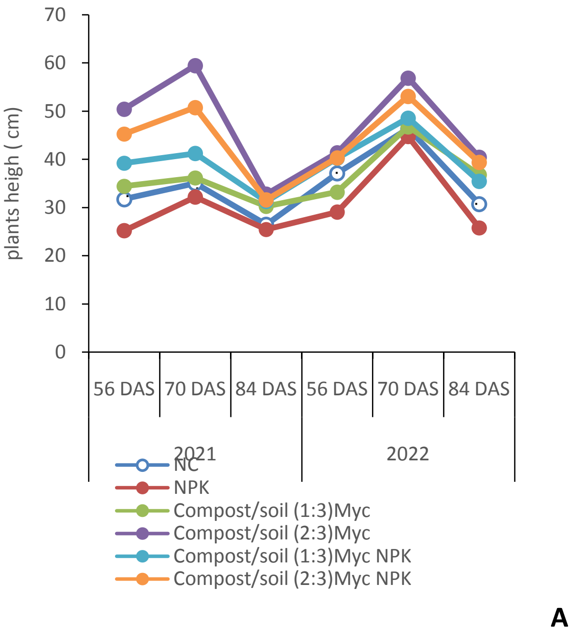
During the 2022 cropping campaign, although the seedlings emergence increased from 14 to 42 DAS, no significant difference was observed between treatments. The germination rate was strongly influenced by different fertilizer receipts, attributed to increased nutrients availability from compost, NPK, or nutrient uptake (mycorrhiza) as previously [31].

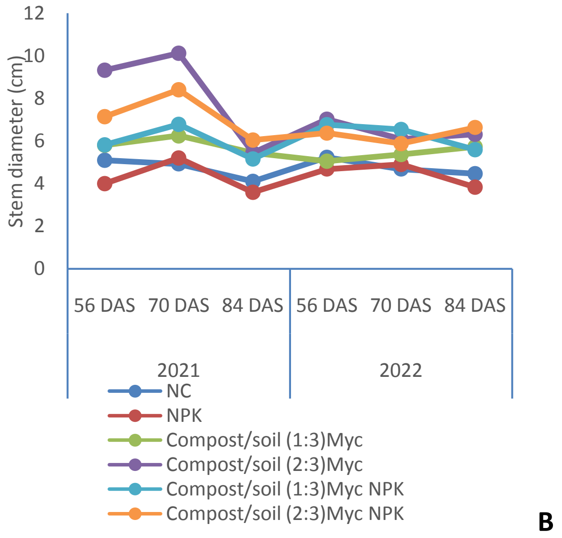
Variation of some *Allium sativum* growth parameters from 42-84 DAS as affected by different fertilization receipts.

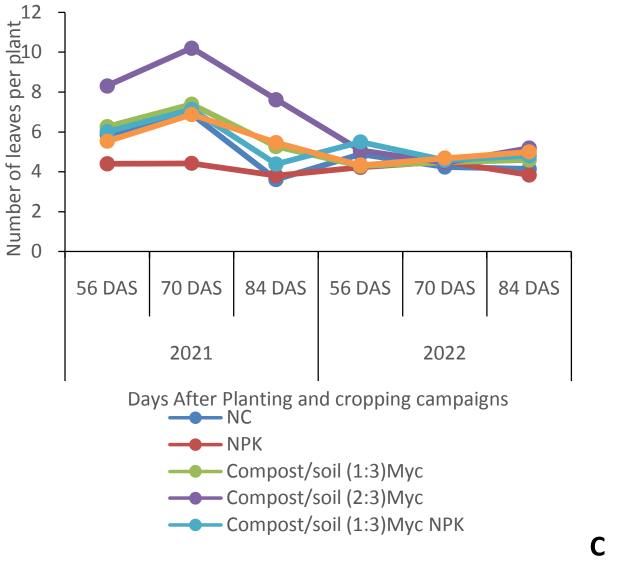
Plant height: Figure 2A presents the evolution of plant height with time (56-84 DAS) as influenced by different treatments. During the (2021, 2022) cropping campaigns, the highest plant growth in height (50.43cm, 41.38cm) at 56 DAS, (59.49cm, 56.89cm) at 70 DAS, (32.79cm, 25.79cm) at 84 DAS were observed from treatment C/S(2:3)+Myc, the positive control recording the lowest plant height, respectively (25.21cm, 29.09cm), (32.17cm, 44.75cm) and (25.45cm, 25.79cm). The maximum plant height was obtained at 70 DAS. It is expected that compost gradually mineralized in the soil and slowly released most of the nutrients [32], while mycorrhiza acted by increasing plant nutrients uptake [2]. These results line with those previously pointing out growth stimulation of *Lycopersium esculentum* [33], and *Solanum tuberosum* [34], after field application of compost at appropriate rate. Moreover, mycorrhizal inoculation in the soil have been reported to increase mineral absorption, thus favoring plant growth, specifically the plant height [35].

Stem diameter: The stem diameter of *Allium sativum* was influenced with time (56-84 DAS) by different treatments (Figure 2B).

During the 2021 and 2022 cropping campaigns respectively, the greatest stem diameter at 56 DAS (9.33mm, 7.03cm), 70 DAS (10.13mm, 6.09cm), 84 DAP (5.44mm, 6.31mm) accounted for treatment C/S(2:3)+Myc, the positive control recording the lowest stem diameter, respectively (4 mm, 4.08mm), (3.17mm, 4.9mm) and (3.59mm, 3.83mm). The maximum stem diameter was obtained at 70 DAS. The increase in the stem diameter under 2:3 compost/soil ratio and mycorrhizal inoculation was the results of improved soil fertility and nutrient uptake by the plant, in agreement with reported increased organic matter content by compost and nutrient availability by mycorrhiza [36]. Mycorrhiza may act by increasing the rhizospheric surface explored by plant roots for water and nutrients uptake such as zinc which is particularly involved in the improvement of *Allium sativum* stem diameter [37]. According to Freire *et al.* [38], AMF benefited plant growth at lower dose of compost and had higher impact on the seedlings shoot diameter.







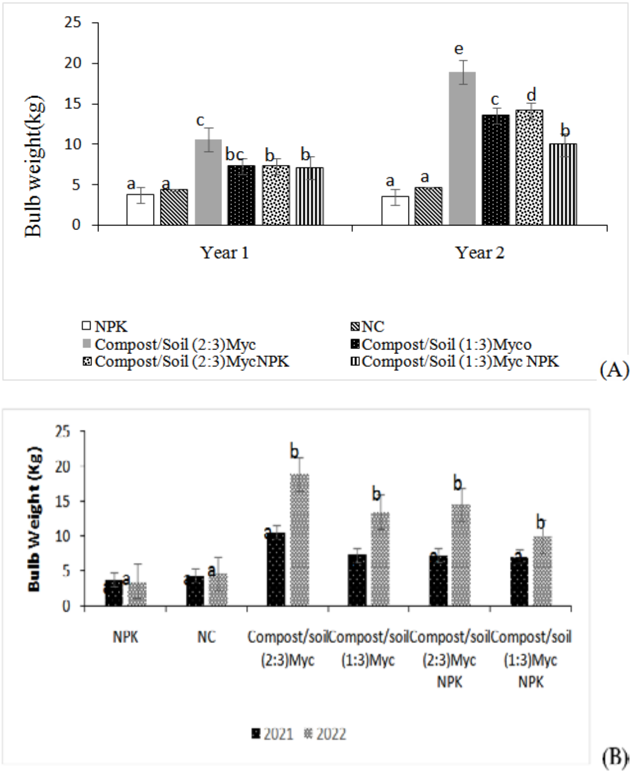
DAS = Days After Sowing; NPK: positive control with NPK: (20:10:10); NC: negative control without any of the fertilizer; C/S-2:3+AMF: compost-soil mixture in the 2:3 ratio with 30g Mycorrhiza; C/S-1:3+AMF: compost-soil mixture in the 1:3 ratio with 30g Mycorrhiza; C/S(2 :3)+AMF+NPK: soil-compost mixture in the 2:3 ratio with 30g Mycorrhiza and 5g NPK; C/S-1:3+AMF+NPK: soil-compost mixture in the 1:3 ratio with 30g Mycorrhiza and 5g NPK.

Figure 2. Yearly evolution of plant height (A), stem diameter (B), leaves/plant (C) with time (56-84 DAS) as influenced by different fertilization receipts

Leaves/plant: The number of leaves on a *Allium sativum* plants increased with the plant development growth phase and varied with the fertilizer receipt applied (Figure 2C). The most effective fertilizer receipt was C/S(2:3)+Myc that increased the number of leaves/plant at 56, 70, 84 DAS during the 2021 (8, 10, 7 leaves /plant), and 2022 (5, 4, 3 leaves/plant) cropping campaigns. In contrast, the lowest number of leaves/plant was obtained at at 56, 70, 84 DAS when plants were applied with the NPK fertilizer (20:10:10), with respectively 4, 4 and 3 leaves/plant during the 2021 and 2022 cropping campaigns. These results are in line with those of Zerga and Tsegaye [39], who reported that the number of leaves/plant and their growth increased with time. The fact that C/S(2:3)+Myc was the best treatment for both cropping campaigns could be attributed to the effect of combined compost-mycorrhiza able to increase the vegetative growth of *Allium sativum*, in conformity with their reported richness in nutritive elements that favors the improved development of auxiliary plant structures [40], in addition its revealed dependency to mycorrhizae [41]. However, the decrease of the studied parameters at 84 DAS was ascribed to the fact that garlic growth parameters reach their maximum values three weeks before the harvesting stage, after which they gradually decreased [42].

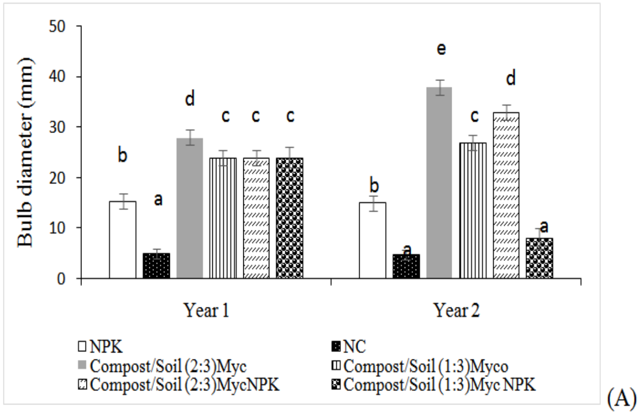
Influence of fertilizer receipts on *Allium sativum* yield parameters

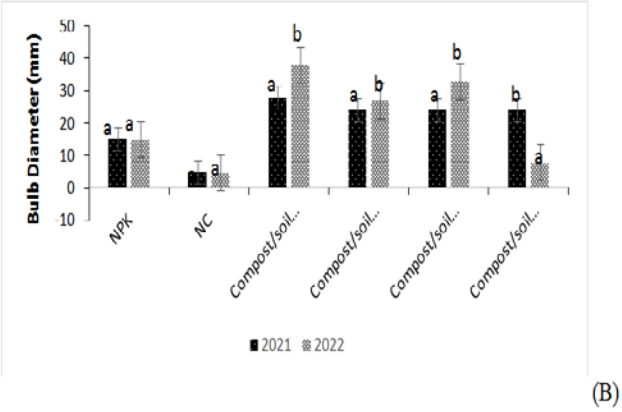
Bulb weight: Figure 3A presents the variation of *A. sativum* bulbs weight from different fertilizers receipts for the two cropping campaigns 2021 and 2022. For both campaigns, treatment C/S (2:3)+Myc had the greatest influence on bulbs weight (10kg, 2021; 18kg in 2022), compared to the negative (3 Kg) and positive (4kg) controls treatments. Whereas the positive and negative controls were not influenced by the cropping campaign, the 2022 campaign significantly increased the bulb weight for each of the other treatments (Figure 3B). Appropriate amount of organic matter was shown to enhance the soil physical conditions, that impact the availability of nutrients (nitrogen, phosphorus, sulfur) with the positive effects on metabolic processes of garlic plants [8,43]. On the other hand, AMF inoculated plants was reported to significantly increase onion bulb weight compared to the non-inoculated plants [37].



NPK: positive control with NPK: (20:10:10); NC: negative control without any of the fertilizer; C/S-2:3+AMF: compost-soil mixture in the 2:3 ratio with 30g Mycorrhiza; C/S-1:3+AMF: compost-soil mixture in the 1:3 ratio with 30g Mycorrhiza; C/S(2 :3)+AMF+NPK: soil-compost mixture in the 2:3 ratio with 30g Mycorrhiza and 5g NPK; C/S-1:3+AMF+NPK: soil-compost mixture in the 1:3 ratio with 30g Mycorrhiza and 5g NPK. For a given parameter, values affected with the same letter are not significantly different between treatments at the indicated probability threshold.

Figure 3. Average weight of *A. sativum* bulbs as affected by different fertilization receipts





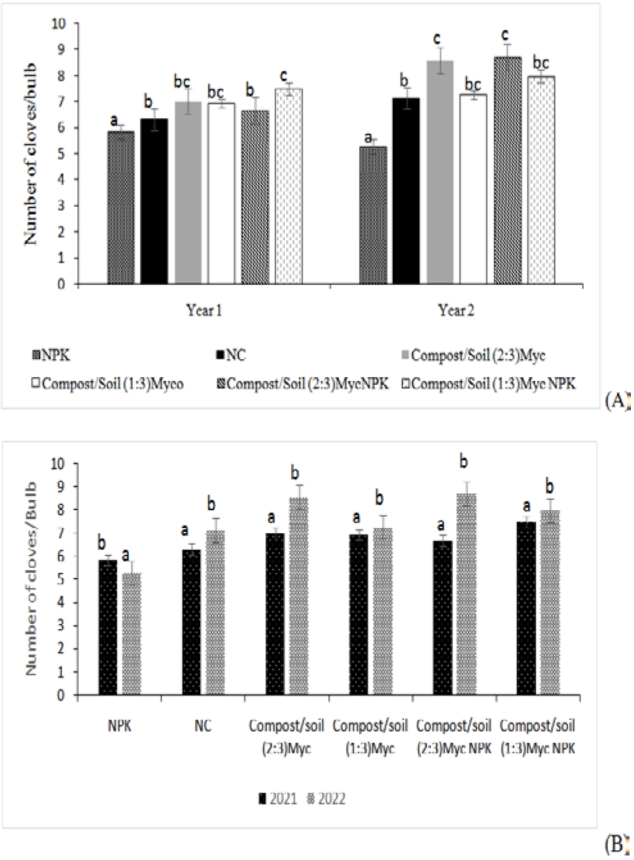
NPK: positive control with NPK: (20:10:10); NC: negative control without any of the fertilizer; C/S-2:3+AMF: compost-soil mixture in the 2:3 ratio with 30g Mycorrhiza; C/S-1:3+AMF: compost-soil mixture in the 1:3 ratio with 30g Mycorrhiza; C/S(2 :3)+AMF+NPK: soil-compost mixture in the 2:3 ratio with 30g Mycorrhiza and 5g NPK; C/S-1:3+AMF+NPK: soil-compost mixture in the 1:3 ratio with 30g Mycorrhiza and 5g NPK. For a given parameter, values affected with the same letter are not significantly different between treatments at the indicated probability threshold.

Figure 4. Variation of *A. sativum* bulbs diameter as affected by different fertilization receipts

Bulb diameters: The *Allium sativum* bulbs diameter significantly (p<0.0001) varied from one fertilizer treatment to another during the 2021 and 2022 cropping campaigns. The highest bulb diameter was obtained from treatment C/S(2:3)+Myc, with 28.29 mm in 2021 and 33.19 mm 2022, whereas the lowest was recorded in the positive control treatment, with only 4.40 and 4.65 mm in 2021 and 2022 respectively (Figure 4A). Apart from the positive and negative control treatments, the other treatments significantly (p = 0.0001) increased the *A. sativum* bulb diameter during the 2022 cropping campaign more than the first campaign of 2021 (Figure 4B). Biofertilizers have been reported to play an important role in cell division and enlargement which are the basal steps of plant growth due to auxins activity [44], with compost known to cause increased physical properties such as bulb diameter of *Allium sativum* plants [9].

Cloves/bulb: The cloves number/bulb significantly (p<0.0001) varied between treatments, with treatments C/S(1:3)+Myc+NPK and C/S(2:3)+Myc recording the highest number of cloves/ bulb (7 cloves/bulb) during the 2021 cropping campaign (Figure 5A), compared to that of the negative control recorded the lowest value (5 cloves/bulb). In 2022, it is rather treatments C/S(2:3)+Myc+NPK and C/S(2:3)+Myc that had the greatest impact on the number of cloves/ bulb (8 cloves/bulb, while the negative control was able to produce only 5 cloves/ bulb on average. For both years, treatments C/S(1:3)+Myc+NPK, C/S(2:3)+Myc and C/S(2:3)+ Myc+NPK recorded the highest number of cloves per bulb (averagely 7 cloves/ bulb). These observations could be attributed to fertilizer applied through treatments. Compost released nutrients for plant growth, while mycorrhiza helped plants to uptake nutrients by extending the root length exploration area. These results are in conformity with those of Shafeek *et al. [9]*, Assefa *et al.* [43], Degmale *et al*. [45], who revealed the significant effects of biofertilizers on increased cloves number/bulb and the average clove weight of garlic plants. Here again, treatments performed better in the second than the first cropping campaign as far as the number of cloves/bulb is concerned (Figure 5B).

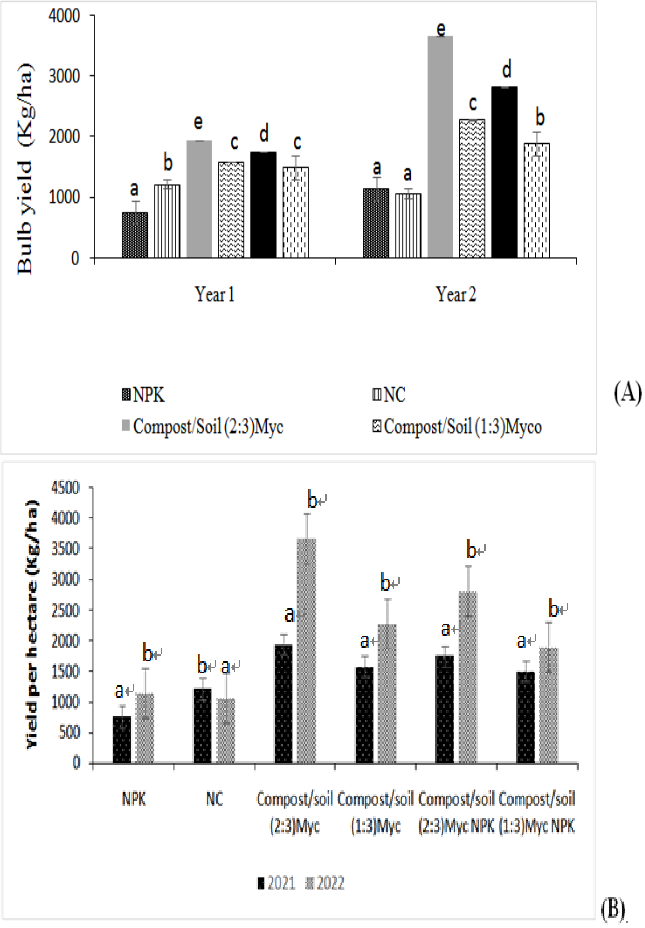
Bulb yield (kg/ha): The *Allium sativum* bulb yield was expressed in Kg/ha, and differed depending on the treatment applied. applied.



NPK: positive control with NPK: (20:10:10); NC: negative control without any of the fertilizer; C/S-2:3+AMF: compost-soil mixture in the 2:3 ratio with 30g Mycorrhiza; C/S-1:3+AMF: compost-soil mixture in the 1:3 ratio with 30g Mycorrhiza; C/S(2 :3)+AMF+NPK: soil-compost mixture in the 2:3 ratio with 30g Mycorrhiza and 5g NPK; C/S-1:3+AMF+NPK: soil-compost mixture in the 1:3 ratio with 30g Mycorrhiza and 5g NPK. For a given parameter, values affected with the same letter are not significantly different between treatments at the indicated probability threshold.

Figure 5. Variation of the number of *A. sativum* cloves/bulb as influenced by different fertilization receipts

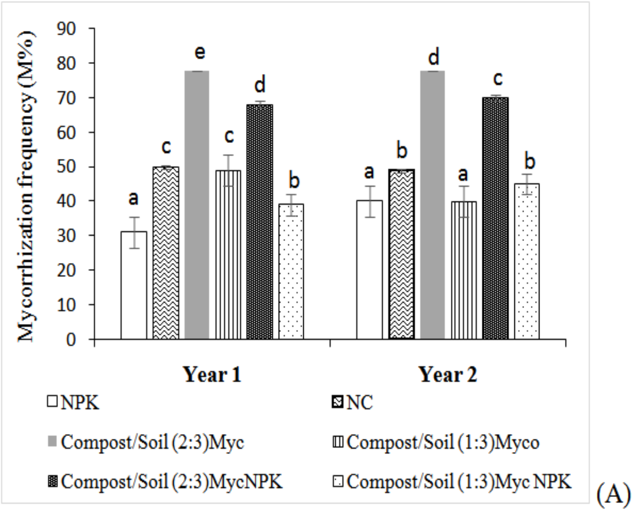
Treatment C/S(2:3)+Myc significantly (p<0.0001) enhanced the bulb yield during the 2021 (1938Kg/ha) and 2022 (3664Kg/ha) cropping campaigns Figure (6A), the lowest yield accounting for NPK-treatment with respectively 756Kg/ha and 1142Kg/ha in 2021 and 2022 cropping campaigns respectively. Bulb yield obtained from the 2022 cropping campaign was significantly greater than that of the previous campaign (Figure 6B). The combined effect compost-mycorrhiza was thus the indicated one in the improved growth and yields of *Allium sativum* plants. Several authors have reported the improve mineral nutrition, growth and yields of inoculated plants with Arbuscular mycorrhizal fungi [43,46,47], while organic fertilizers such as compost was revealed to positively for increase garlic growth and productivity [48].

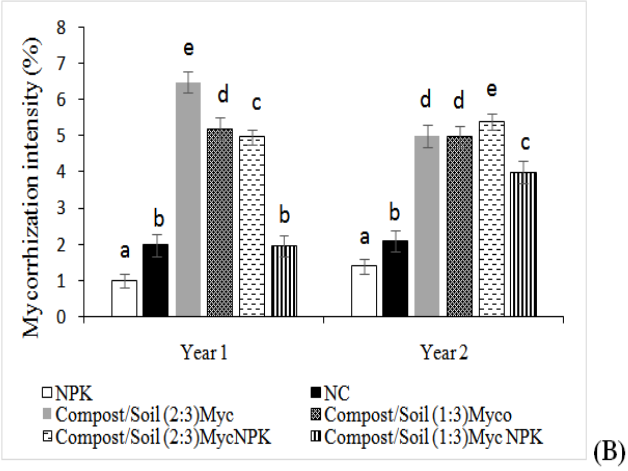


NPK: positive control with NPK: (20:10:10); NC: negative control without any of the fertilizer; C/S-2:3+AMF: compost-soil mixture in the 2:3 ratio with 30g Mycorrhiza; C/S-1:3+AMF: compost-soil mixture in the 1:3 ratio with 30g Mycorrhiza; C/S(2 :3)+AMF+NPK: soil-compost mixture in the 2:3 ratio with 30g Mycorrhiza and 5g NPK; C/S-1:3+AMF+NPK: soil-compost mixture in the 1:3 ratio with 30g Mycorrhiza and 5g NPK. For a given parameter, values affected with the same letter are not significantly different between treatments at the indicated probability threshold.

Figure 6. Differences in *A. sativum* bulb yield (Kg/ha) as affecteded by different fertilization receipts.

Status of the mycorrhization intensity and rate in *Allium sativum* roots





NPK: positive control with NPK: (20:10:10); NC: negative control without any of the fertilizer; C/S-2:3+AMF: compost-soil mixture in the 2:3 ratio with 30g Mycorrhiza; C/S-1:3+AMF: compost-soil mixture in the 1:3 ratio with 30g Mycorrhiza; C/S(2 :3)+AMF+NPK: soil-compost mixture in the 2:3 ratio with 30g Mycorrhiza and 5g NPK; C/S-1:3+AMF+NPK: soil-compost mixture in the 1:3 ratio with 30g Mycorrhiza and 5g NPK. For a given parameter, values affected with the same letter are not significantly different between treatments at the indicated probability threshold.

Figure 7. Mycorrhization frequency (A) and intensity (B) as influenced by yearly fertilization receipts.

Allium sativum roots infection by AMF occurred in all treated plants, including the un-inoculated plants or negative control, suggesting the ubiquitous nature of the fungus, occurring naturally in most agricultural soils [49,50]. For both experimental years, mycorrhization frequency was significantly higher in root of C/S(2:3)+Myc treated plants during the 2021($p = 0.0001$) and 2022 ($p = 0.002$) cropping campaigns than that of other treatments (Figure 7A). Treatments NPK and C/S(1:3)+Myc+NPK recorded the lowest mycorrhization frequency values. During the 2021 cropping campaign, the intensity of mycorrhization in plant roots was significantly enhanced by treatment C/S(2:3)+Myc, compared to the lowest values from treatments NPK, NC, or C/S(1:3) +Myc+NPK (Figure 7B), However, no significant difference was found in the mycorrhization intensity values between treatment NC and C/S(1:3)+Myc+NPK. The highest values of mycorrhization intensity were recorded from C/S(2:3)+Myc+NPK, C/S(2:3)+Myc and C/S(1:3)+Myc roots, the lowest accounting for treatment NPK and NC during the 2022 cropping campaign. The poor root colonization by the native AMF compared to the applied inoculum could be attributed to inefficiency of the native-derived AMF [51]. The contribution of compost/soil in the 2:3 ratio, inoculated with mycorrhiza and applied with inorganic fertilizers (NPK) resulted in low mycorrhization frequency, indicating that excessive soil fertilization affects mycorrhization rate of *A. sativum*. These results confirm those of Haro *et al.* [47], who showed that excess availability of nutrients in the soil reduces mycorrhization. Treatment C/S(2:3)+Myc recorded a mycorrhization frequency and intensity above 80% [52], suggesting that the plant establishes a functional symbiosis with the fungus[53], although mycorrhization frequency of less than 45% have been reported in other studies [54]. However, the mycorrhization intensity has remained low compared to mycorrhization frequency, in line with a negative correlation previously reported between the two parameters [46]. Treatments NPK and C/S(1:3)+Myc+NPK recorded the lowest mycorrhization frequency values. During the 2021 cropping campaign, the intensity of mycorrhization in plant roots was significantly enhanced by treatment C/S(2:3)+Myc, compared to the lowest values from treatments NPK, NC, or C/S(1:3) +Myc+NPK (Figure 7B), However, no significant difference was found in the mycorrhization intensity values between treatment NC and C/S(1:3)+Myc+NPK.

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4. Conclusion

Results of this study clearly revealed that productivity of garlic positively responded and in repeated cropping campaigns to the integrated application of compost-soil (2:3) inoculated with 30g mycorrhiza. Additional application of 5g NPK-fertilizer to compost-soil-mycorrhiza mix was detrimental to garlic growth, because of excess nutrients that reduced the host-plant mycorrhization frequency and intensity. Whereas organic treatment increased the soil pH from 6.07 prior-cultivation to 6.8 at post-harvest, the soil Mg, Ca and phosphate contents were instead reduced in post-harvest soil following assimilation by the host plant, while the organic matter content was significantly enhanced due to improved soil fertility by compost. On the overall, it is necessary to supplement soil-plant rhizosphere with compost in the 2:3 ratio (compost/soil), and additionally inoculated it with 30g mycorrhiza, while avoiding any NPK-fertilizer, to significantly improve not only the growth and yield parameters of Allium sativum, but also enhance the soil physico-chemical properties at post-harvest.

Conflict of Interest

The authors are hereby declaring that no conflict of interest exists.

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