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Improving Potato Productivity and CO_2 Sequestration by Using Organic Amendments and Foliar Calcium Application

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Abstract

The necessity to conserve limited natural resources requires the investigation of alternative methods to improve food production while ensuring environmental sustainability. Using organic amendments can play a vital role in crop production and soil health. In this context, the performance of vermicomposting as an effective tool for converting organic waste materials into valuable organic amendments, integrated with foliar Ca supply at different rates, was investigated on a strategic potato crop (*Solanum tuberosum*, L.) cv. Sponta production system, compared to the traditional organic amendment of cattle manure, which is also integrated with foliar Ca supply. Two successive summer seasons of 2022 and 2023 were conducted under open field conditions at the Central Laboratory for Agriculture Climate (CLAC), Agriculture Research Centre. A split-plot design was applied using vermicompost (20 m^3/acre) compared to cattle manure at the same rate, combined with rates of foliar calcium application (0.0, 0.5, 1.0, and 1.5% calcium nitrate). The results indicated that integrating vermicompost organic waste with foliar calcium application significantly improved potato production, outperforming traditional amendment of cattle manure. Vermicompost with foliar calcium application improved potato yield, increased CO_2 sequestration in the soil, maintained soil health and promoted environmental sustainability.

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Keywords: Sustainability, Vermicompost, Cattle Manure, Foliar Calcium Application, Potatoes Production and CO_2 Emissions

INTRODUCTION:

It is widely recognized that the world now relies on sustainable development for securing the growth, prosperity, and welfare of next generations. Sustainable agriculture is a key to sustainable development and crucial for achieving the goal of "Zero Hunger" and climate change mitigation. It ensures that food production is efficient, environmentally friendly, and economically viable in the long term. Continuity in unsustainable practices leading to ecosystem vulnerability and waste of resources, putting agricultural growth, food security and climate change mitigation at risk **(IPCC, 2014 & Ahmed, 2022; Hiywotu, 2025).**

Egyptian soil is suffering from nutrient leaching, a reduction in microbial activity, and the contamination of water and the surrounding environment, ultimately resulting in the depletion of our resources (**Hoque *et al.*, 2022**). According to **Shereen, *et al.* (2017**), mineral fertilizers with intensive cropping systems create infertility and unfavourable soil conditions which are lowering the percentage of soil organic matter, and available nutrients due to its continuous depletion by crops without adequate replenishment over the time, these act as an immediate threat to yields and soil health. On the other hand, continuous additions of organic fertilizers increase the microbial biomass and stimulate enzyme activities which have positive effects on both soil aggregation and macro porosity which reflect on the biological decomposition producing more organic matter content in soil, lead to improving of the production system (**Hoque, *et al.*, 2022, Das, *et al.*, 2022 and Otieno, 2024**).

Agricultural wastes is expected to increase intensely due to rapid urbanization and population growth, reaching an estimated 3.4 billion tons by 2050, with an increment 70% from 2016. Food waste alone is responsible for nearly 50% of gas emissions and is expected to rise to 2.38 billion tons of CO_2 equivalent by 2050 (**Fernando and Arunakumara, 2021**). Despite the challenges posed by organic waste, it can also be a valuable resource for improving soil health and plant growth. This can be achieved by earthworms through biological processes that converting organic wastes into valuable organic fertilizer called 'vermicompost', helps to solve the waste problem, promote growth and reduce greenhouse gas emissions (**Raza, *et al.*, 2022**).

Vermicompost properties make it highly effective in maintaining adequate soil fertility. Vermicompost is a valuable source of organic matter, nutrients and beneficial microorganisms for plants. It's not only improves the physical and chemical properties of the soil but also stimulates biological processes and useful interactions between soil microorganisms and plants, such as the symbiosis relationship between legumes and rhizobia (**Hoque, *et al.*, 2022 and Carol, *et al.*, 2025**). In addition, vermicompost is favourably influential on all parameters related to crops productivity (**Sinha, *et al.*, 2009 and Mishra, *et al.*, 2022**). These properties enable vermicompost to promote various production systems, especially for environmentally stress-sensitive crops like Potatoes, leading to the cultivation of high-value crops and increased production, thus contribute to addressing food shortages and expanding export markets.

Potatoes (*Solanum tuberosum* L.) are one of Egypt's seven most strategically important agricultural crops, alongside cotton, maize, rice, sugarbeet, sugarcane, and wheat. In Egypt, potato production uplifting is urgently required to fulfil the growing demand of an ever-increasing population because it is an inexpensive resource of energy with high nutritional value and carbohydrate, it increasingly serves as feedstock for industrial products and it is a second-largest exported horticultural crop after citrus (**Anonymous, 2017**).

Potato growers, in particular, are suffering significant post-harvest losses of potato tubers as a result of calcium deficiency, which creates favourable conditions for pathogen infection, where calcium is one of the most important factors can enhance resistance to bacterial phytopathogens (**Ngadze, *et al.*, 2014** and **Ferreira, *et al.*, 2024**). According to **El-Hadıdı, et al. (2017)**, calcium is essential during the rapid growth phase of tubers and can enhance tuber quantity and quality. Calcium application through foliar methods enhances potato growth and increases tuber yield and superior quality under the Egyptian climate. Also, **El-Morsy, *et al.* (2020)** added that supplemental foliar calcium application is essential for the vigorous leaf and root system, and prevents physiological tuber disorders. The availability of adequate calcium near cell membranes keep integrity and increases the rigidity of the cell wall and assists plants in their adaptation to stress (**Thiruvengadam, *et al.*, 2025**). Besides, Calcium plays a crucial role in regulating the active transport of potassium, which regulates stomatal opening, mitigates summer heat stress and minımızıng wilting and leaf damage, which helps in potentially increasing yield by 30%. Moreover, calcium acts as a plant hormone, regulating various growth processes. (**Role of Calcium in Potato Production, 2022).**

The terrestrial ecosystem is intricately connected to atmospheric CO_2 concentrations through the processes of carbon sequestration in both soil and biomass. Numerous factors have been identified as significant contributors to CO_2 and other gas emissions from the terrestrial systems. These factors include organic carbon content, soil texture, pH levels, water-filled pore space, as well as the type and duration of crops grown (**Shakoor *et al.*, 2020**). Animal manure is responsible for approximately 37% of global greenhouse gas emissions; however, its application as a soil amendment can significantly reduce this figure (**Vac, *et al.*, 2013**). Annually, around 7.0 billion tons of animal manure are utilized on agricultural lands (**Thangarajan, *et al.*, 2013**). Research by **Gattinger, *et al.* (2012**) indicates that the incorporation of animal manure in soil can enhance its carbon content and transform it into a net sink for CO_2.

The present paper aims to investigate the performance of vermicompost and cattle manure as organic amendments combined with calcium treatments to improve the potato production system and study the effect of these treatments on microbial activity and the mitigation of CO_2 emissions to achieve sustainable agricultural goals.

2. MATERIALS AND METHODS:

Experiments of this work were carried out at the Central Laboratory for Agriculture Climate (CLAC), Agriculture Research Centre, Giza, Egypt (30° 03\` N latitude, 31° 20\` E longitude and mean altitude 70 m above sea level), Before cultivation, chemical and physical properties of the experimental soil were analyzed following the methods outlined by **Chapman and Pratt (1961**), the analysis clarifies that the used land is fertile and has suitable pH, salinity and physical properties **(Table 1)**.

2.1. The field experiment: The field trial involved the cultivation of Potato (*Solanum tuberosum*, L.), cv. Sponta. in an open-field setting. Tubers sowing was done on the second of February 2022 and 2023 for the two growing seasons with 30 cm planting distances and 70 cm distances between rows. Potato tubers, cut into small pieces with two to four eyes, were treated with fungal materials and allowed to germinate for two weeks. Potato plants were irrigated during the experiment by using drippers of 2 l/hr capacity and three emitters per lateral meter. The chemical fertilizers were injected through the drip irrigation system. The fertigation was programmed to work twice a day, the irrigation duration time varied depending on weather conditions. All other agricultural practices for potato cultivation adhered to the standard recommendations for commercial growers provided by the Agriculture Research Center (ARC), Ministry of Agriculture, Egypt. (**Vegetable Cultivation Guide, 2014).**

Table (1): Chemical and physical analyses of the soil (20-30cm depth) at Dokki site before cultivation.

Chemical properties							
ECe dS/m	pH	Ca++ mg/L	Mg++ mg/L	Na+ mg/L	K+ mg/L	Hco3- mg/L	CL- mg/L
2.53	7.2	4.95	1.7	8.4	4.45	2.6	9.83
Physical properties							
Sand %	**Clay %**	**Silt %**	**Texture**	**SP%**	**FC %**	**WP %**	**BD g/cm^3**
24.3	55.9	19.8	Clay	21.7	33.0	15.0	1.35

SP: storage pore, FC: field capacity, WP: wilting point, BD: bulk density

2.2. Used organic amendments and the experimental treatments: Vermicompost and cattle manure were used in this study as organic amendments. Vermicompost was prepared by using the epigeic earthworms *Lumbriscus rubellus* (Red Worm), *Eisenia fetida* (Tiger Worm), *Perionyx excavatus* (Indian Blue), and *Eudrilus eugenia* (African Night Crawler) on the mixture of the raw materials: cattle manure + kitchen wastes + newspaper (2: 2: 1) according to **Wako (2021).** Earthworms were obtained from the vermicompost unit belonging to CLAC. Cattle manure was taken from the same amount used in preparing vermicompost, which was obtained from a private cattle farm. Vermicompost and cattle manure were applied at a rate of 20 m³/acre, combined with various foliar calcium applications (0.0%, 0.5%, 1.0%, and 1.5% calcium nitrate), using cattle manure with this rate is considred the control treatment (personal communication with potato farmer). The organic amendments were added after soil preparation, two weeks before cultivation.

2.3. Microbial count of used material and soil: Microbial plate counts were conducted according to the method described by **Trevors and Cook (1992**). One gram of dry cattle manure or vermicompost was suspended in 100 mL of sterile distilled water in a conical flask and stirred at 80 rpm for 2 minutes. The suspension was then allowed to settle for 1 hour before being serially diluted to the concentrate 10^{-10} .To estimate the fungal population, 1 mL of each solution was placed onto plates of potato dextrose agar medium supplemented with streptomycin (100mg / L) before pouring. The plates were then incubated at 27 ± 1 ° C for 48 hours, and the total fungal count (TFC) was determined. Total bacterial count

(TBC) was determined by plate count method on nutrient soil extract agar medium (LMG medium 30: Agar 15g, yeast extract 2g, peptone 5g. NaCl 5g, Lab. Lemco beef extract 1g, soil extract 1L, pH 7.2 at 25˚ C in 1L of tap water) with incubation at 30˚C for 48h (**Jacobs and Gerstein, 1960**). The count of spore-forming bacteria (TSC) was carried out by plating the same medium but after heating the serial dilutions at a temperature of 80˚ C for 15 minutes with incubation at 30˚C for 48h (**Clark, 1965).** In soil microbial count values of TBC and TSC were recorded using the function LOG10+2.

2.4. Effect of used organic amendments on soil carbon mineralization

***2*.4.1 Evolution of the rate of CO_2 efflux:** The evolution of the rate of CO_2 efflux resulting from microbial activities in the rhizosphere soil was performed in the laboratory according to the method described by **Promer and Schmidt (1964**) and modified by **Shehata (1972),** which depends on the reaction of elevated CO_2 captured with NaOH solution with barium chloride to give a red color which changed to colorless by acidic titration using HCL. The evolution of the rates of emitted CO_2 were calculated according to the following equation (**Alef & Nannipieri, 1995):**

CO_2 (mg)/sw/t = (V°-V) x 1.1/dw, Where:

sw = the amount of planting medium (soil) dry weight in grams.

t = the incubation time in hours.

V° = volume (ml) of HCl (0.05M) used for the blank.

V = volume (ml) of HCI used for planting medium sample.

dw = the dry weight of 1g moist planting medium.

1.1 = the conversion factor (1ml 0.05M NaOH= 1.1 mg CO_2).

2.4.2. The cumulative gas emission fluxes: The cumulative CO_2 emission fluxes between the two sampling times were calculated according to the following equation (**Nigussie et al.,2016 and Li, et al., 2025**) :

$$C = (Tb - Ta) \times (Fa + Fb) / 2$$

Where: C is the cumulative CO_2 emission between sampling times Ta and Tb ($mg \cdot g^{-1}$), and Fa and Fb are the gas emission fluxes at Ta and Tb, respectively ($mg.\ g^{-1} \cdot d^{-1}$).

2.5. Chemical analysis of used organic amendments and soil: At the beginning of the experiment chemical and microbial analysis of used organic amendments was estimated (**Page *et al,* 1982**). The soil organic matter of the experiment area was measured before soil amendment application and after the harvesting of potato tubers in both the first and second seasons. Available calcium (mg/100g soil) were determined in soil profiles 0-20 and 20- 40, before and after growing seasons. The available soil nutrients N, P and K (mg/kg soil) before and at the end of growing seasons were determined in the 30 cm soil profile depth (**A.O.A.C., 2005**).

2.6. Plant growth and yield parameters and chemical analysis*:* The growth parameters plant height (cm), number of leaves per plant, fresh and dry weight (g/plant), total leaves area (cm^2) using a leaf area meter, total chlorophyll content (mg/g) using chlorophyll meter (Spad-501; Minolta Co., Japan) were taken at the mid of development stage. The crop yield measurements were total tuber yield in number per plot and per acre, total tuber yield in weight per plot (kg) and per acre, which was sorted according to the Ministerial Decree No. 651/1978 issued by the Egyptian Organization for Standardization and Quality Control (EOS), marketable and unmarketable yield in weight per plot (kg). Tubers firmness was also measured using a Magness and Ballouf pressure tester equipped with 3/16 inch plunger as g / cm^2 according to **Wills *et al.* (1982).** The tuber volume of ten tubers was determined in cm^3 by measuring the water volume displaced by immersing the tuber in 2L graduated cylinder. Also, Total carbohydrates were determined as g/100g dry weight according to **Smith *et al.* (1956**). Whereas, starch was determined as g/100g dry weight by subtracting the total soluble sugars from the total carbohydrates according to **A.O.A.C. (1975).**

For mineral analysis of leaves N, P, and K % determinations were taken place at the same time of taking plant growth and yield parameters. Samples from each plot were dried at 70˚C in an air-forced oven for 48h, and dried leaves were digested in concentrated H_2SO_4 solution according to the method described by **Allen (1974).** Total nitrogen was determined by the Kjeldahl method according to the procedure described by **FAO (1980**). Phosphorus content was determined by using a spectrophotometer according to **Watanabe and Olsen (1965).** Potassium content was determined photo-metrically using the Flame photometer as described by **Chapman and Pratt (1961).**

2.7. Statistical analysis: Collected data were subjected to a combined analysis of variance (ANOVA) utilizing a split-plot design, according to **Gomez and Gomez (1984).** Prior to this combined analysis, Levene's test (**Levene, 1960**) was conducted to assess the homogeneity of individual error terms. To determine statistically significant differences between means, the least significant difference (LS.D) test was applied at a probability level of 0.05.

3. RESULTS:

3.1 Chemical and microbial analysis of used organic amendments:

Table (2) demonstrates that vermicompost prepared from cattle manure, kitchen waste, and newspaper in a ratio of 2:2:1, exhibit markedly elevated concentrations of nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg) compared to the nutrient composition of the cattle manure utilized. C/N ratio of vermicompost was 13.6, while it was 21.7 for cattle manure indicating that vermicompost contain higher level of nitrogen. **Table 3** represents the detected microbial communities in the used vermicompost and cattle manure samples. There were noticeable significant differences in microbiological parameters between cattle manure and vermicompost, where TBC was significantly higher in the vermicompost sample, while TFC and TSC were significantly higher in the cattle manure sample.

Table (2): The chemical composition (%) of used vermicompost and cattle manure.

Material	C/N ratio	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
Vermicompost	13.60	1.43	0.57	9.03	0.97	0.82
Cattle manure	21.70	1.20	0.45	7.71	0.83	0.62

Table (3): Microbial plate counts for used vermicompost and cattle manure.

	TFC	TBC	TSC
Vermicompost	68 * 10 b	250 * 10^{10}a	35 * 10^{2}b
Cattle Manure	65 * 10^{2}a	277 * 10^{8}b	55 * 10^{4}a

* Similar letters indicate nonsignificant at 0.05 levels

* TFC:Total Fungi count; TBC:Total Bacterial count; TSC:Total Spore Forming count

3.2 Soil microbial count, soil carbon mineralization and the cumulative gas emission fluxes:

Table (4) shows the microbial communities and their activity in mineralization based on the evolution of CO_2 efflux (mg.g^{-1}.d^{-1}) as affected by the treatments after one and two months of cultivation. Cumulative gas emission fluxes (CGEF) were also calculated. The results revealed distinct differences in soil microbial communities following the application of vermicompost and cattle manure, which evolved over time.

The recorded data shows the significant high value of total fungi (TFC) and total bacterial count (TBC) by applying vermicompost with the highest level of calcium spraying (1.5% Ca) after one and two months of cultivation, when compared to the control (Cattle manure + 0.0% Ca), while, it recorded the lowest value of total spore-forming bacteria (TSC). The highest values of TSC were recorded with the treatments of Vermicompost+ 0.0% Ca and Vermicompost+ 0.5% Ca, respectively. The lowest CO2 efflux was observed after two months, when applying the treatments of vermicompost combined with 1.0% calcium and cattle manure combined with 1.5% calcium, yielding values of 0.52 and 0.54 mg.g-1.d-1, respectively. While, CGEF which refer to the CO2 emissions during thirty days, was in highest values (28.7 and 28.7 mg.g-1) with the treatments vermicompost + 0.5% and vermicompost + 1.0%, while it was in the lowest value with the treatment of vermicompost + 1.5% (19.4 mg.g-1) although of giving highest CO_2 efflux after one month of cultivation (1.13 mg.g-1.d-1). A notable finding from Table 4 is that applying calcium, regardless of the used rate, significantly influenced the microbial community by increasing the total bacterial count and CO_2 efflux after applying either vermicompost or cattle manure.

Table 4: Microbial count and CO_2 efflux one and two month after seedling.

Variable		TFC (CFU/ml)		TBC (CFU/ml)		TSC (CFU/ml)		CO2 efflux (mg.g^{-1}.d^{-1})		CGEF (mg.g^{-1})
		1m	2m	1m	2m	1m	2m	1m	2m	
Amendments, A										
Vermicompost		214.63b	43.00b	3.65a	3.88a	0.73b	0.99b	0.84a	0.77a	24.2
Cattle manure		234.16a	64.47a	2.41b	2.15b	1.15a	1.31a	0.69b	0.55b	18.6
Foliar Ca Application, B										
0.0 %		199.07b	19.77c	2.89d	2.75d	0.68d	1.35a	0.72c	0.73a	21.8
0.5 %		194.00b	26.16c	3.04c	2.86c	0.76c	1.30a	0.82b	0.72a	23.1
1.0 %		393.00a	102.67a	3.06b	3.16b	0.92b	1.06b	0.96a	0.59b	23.3
1.5 %		111.50c	66.34b	3.12a	3.24a	0.98a	0.89c	0.97a	0.59b	23.4
A x B										
Vermicompost	**0.0 %**	58.16c	20.53d	3.48c	3.50c	1.27a	1.51a	0.77d	0.86a	24.5
	0.5 %	71.67c	29.33c	3.64c	3.69c	1.09b	1.44a	0.65e	0.64ab	28.7
	1.0 %	119.33c	91.00b	3.76b	3.99b	0.79c	1.24b	0.88bc	0.52c	28.7
	1.5 %	617.33a	117.00a	3.94a	4.21a	0.63d	1.05c	1.13a	0.78a	19.4
Cattle manure	**0.0 %**	347.96b	19.00d	2.19e	2.00e	0.73c	1.69a	0.88bc	0.63b	22.7
	0.5 %	316.33b	23.00cd	2.45d	2.04e	0.73c	1.67a	0.85c	0.63b	22.2
	1.0 %	168.67c	41.67c	2.47d	2.12e	0.70d	1.28b	1.09a	0.82a	21.0
	1.5 %	103.67c	88.33b	2.52d	2.45d	0.75cd	1.25b	0.80d	0.54bc	20.1

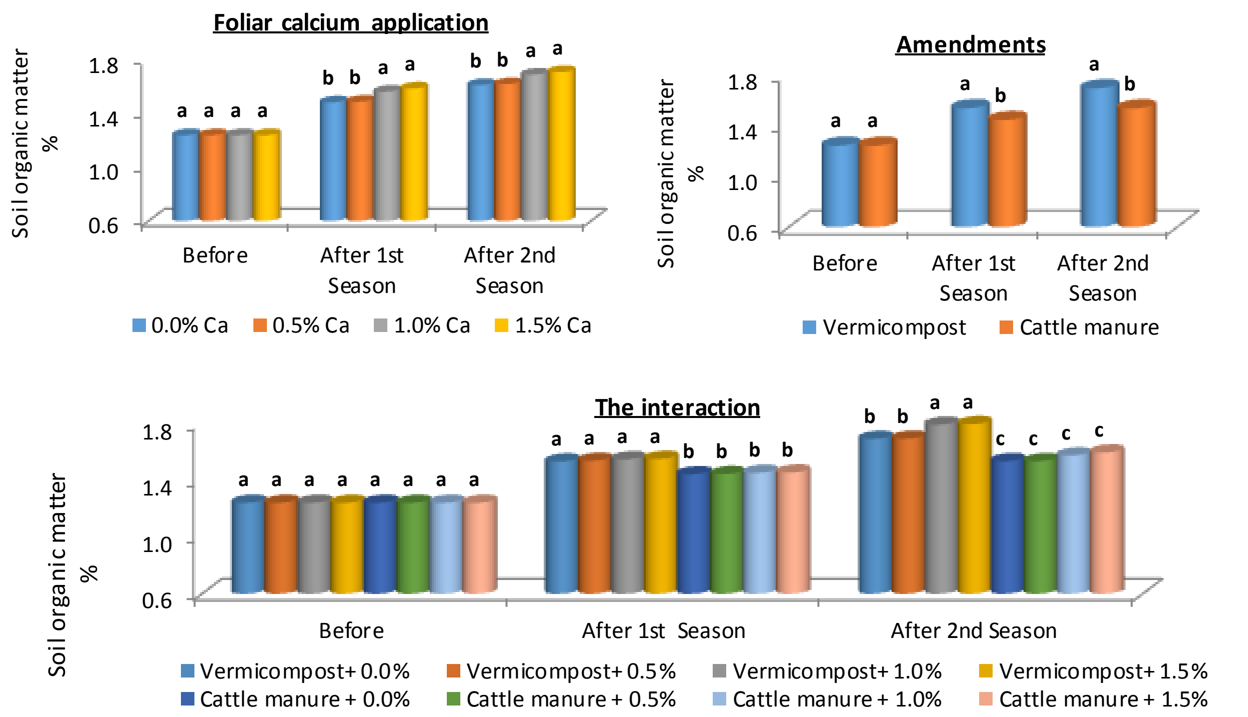
* Control treatment is the treatment (Cattle Maure + 0.0 % of Ca)
* Similar letters indicate nonsignificant at 0.05 levels.
* TFC: Total Fungal count ; TBC: Total bacterial count; TSC: Total Spore Forming count; CGEF = The cumulative gas emission fluxes, 1m = after one month and 2m= after two months.
* Numbers of TBC and TSC were subjected to the function (LOG10+2).

3.3. Organic matter content in soil:

Figure 1 represents soil organic matter content (SOM), a key indicator of soil fertility. It was measured before applying soil amendments and after the harvest of potato tubers in the first and second seasons. **Figure 1** demonstrates that SOM significantly increased with the addition of vermicompost compared to cattle manure, particularly after the second season. There was no clear significant variation in SOM with the foliar calcium application. The combined application of vermicompost at a rate of 20 m³/acre and various foliar calcium concentrations consistently outperformed cattle manure at the same rates of calcium concentrations.

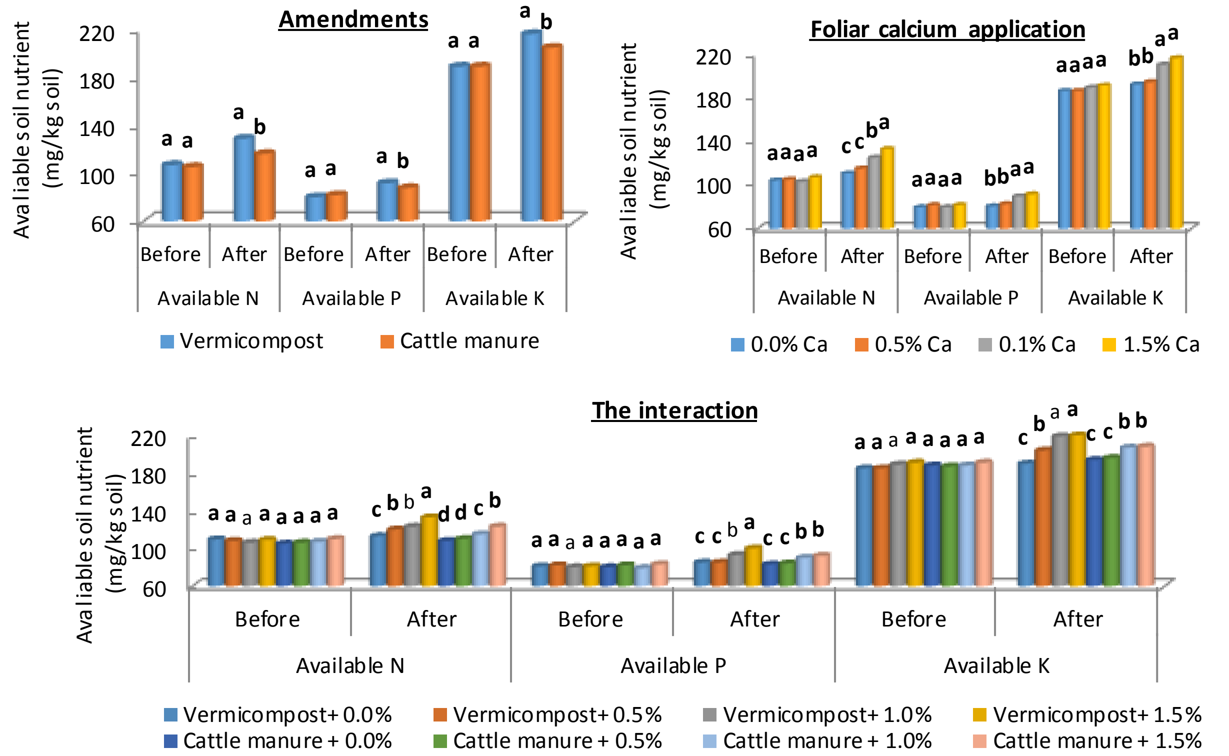
3.4. The presence of nitrogen (N), phosphorus (P), and potassium (K) within the soil profile:

Data in **Fig. 2** reveal the availability of nutrients (N, P and K) before and at the end of growing seasons the depth of 30 cm of soil profile. Vermicompost significantly enhanced the availability of N, P and K better than cattle manure. Using calcium application increased the studied nutrient availability, especially N, with the high rate of calcium application (1.5 %). Using vermicompost combined with the highest rate of calcium showed a significant increase in soil content of N, P and K. It is also noted that these soil nutrients increased with the use of organic matter additives, whether vermicompost or cattle manure, at the end of the growing seasons compared to at the end of the growing seasons compared to the condition before adding any organic matters. Regarding the interaction between treatments, it was found that the addition of vermicompost and calcium at the highest rate contributed to increasing the availability of various measured elements in the studied soil at the end of the growing season.



* Control treatment is the treatment (Cattle Maure + 0.0 % of Ca) * Similar letters indicate nonsignificant at 0.05 levels.

Fig. (1): The soil organic matter content (%) of the soil's experiment before planting and after the first and second seasons.

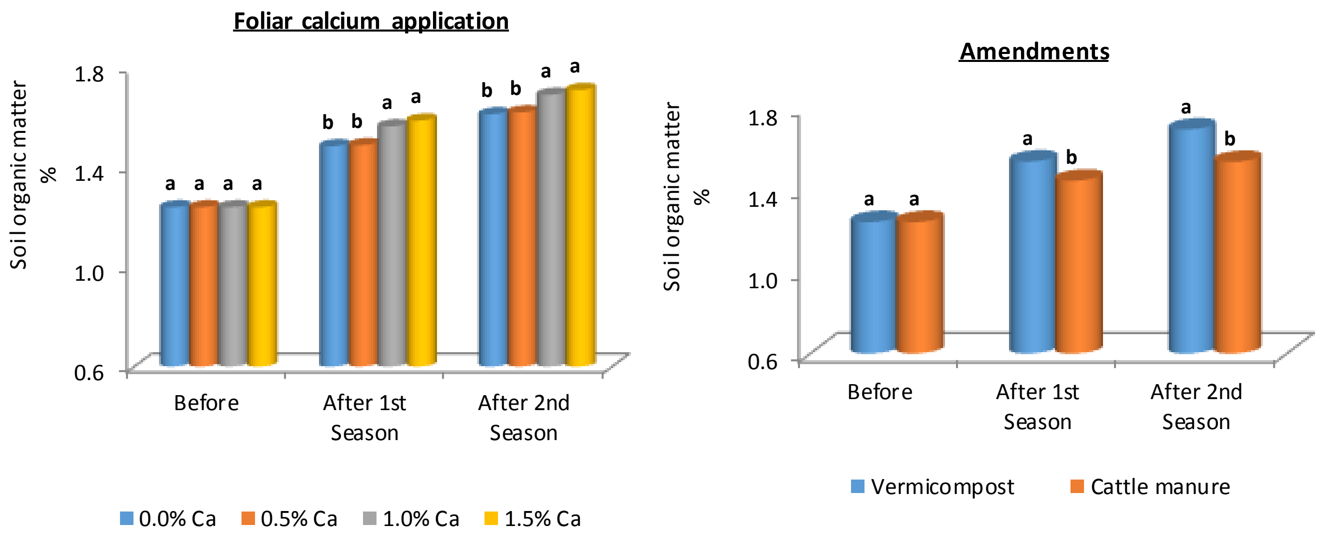


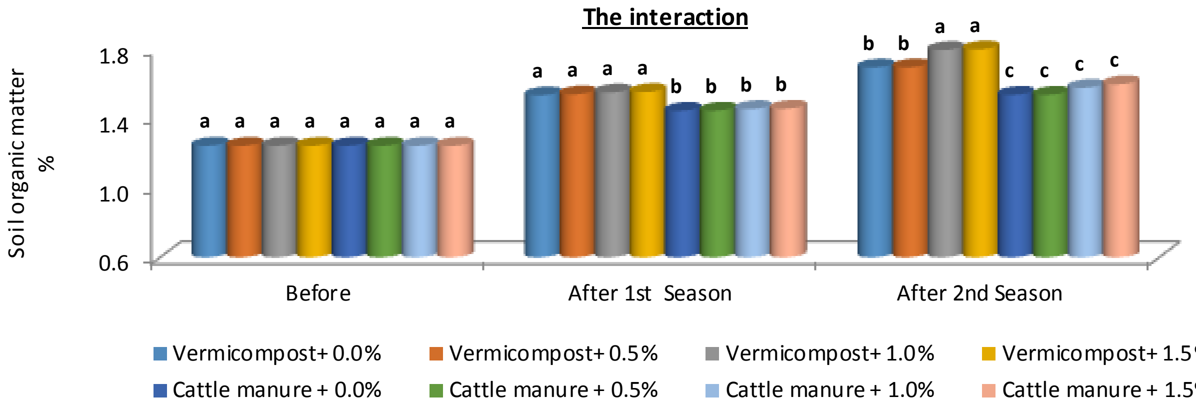
* Control treatment is the treatment (Cattle Maure + 0.0 % of Ca) * Similar letters indicate nonsignificant at 0.05 levels.

Fig. (2): Avaliable soil nutrients N,P and K (mg/kg soil) of the soil's experiment before and the end of growing seasons.

3.5. Available calcium in the different soil profiles

Data in **Fig. 3** shows the response of soil calcium content to the studied treatments. Available calcium in the soil increased with both treatments, especially after the second season. The calcium available in the first layer of the soil profile was more than in the second layer. Vermicompost enriched the quantity of soluble calcium in both soil profile depths compared to the cattle manure, especially combined with a 1.5% rate of foliar calcium. Vermicompost with 1.5 % foliar calcium at the 0-20 cm layer showed the highest value of the available calcium.





* Control treatment is the treatment (Cattle Maure + 0.0 % of Ca)
* Similar letters indicate nonsignificant at 0.05 levels.

Fig. (3): Soluble calcium in the different soil profiles before planting and after the first and second seasons.

3.6 The effect of used organic amendments on some growth parameters:

The growth parameters plant height (cm), number of leaves/plant, fresh and dry weight (g/plant), total leaf area (cm^2), and total chlorophyll content (mg/g) were measured and showed in Table 5. Significant differences between treatments were found during both seasons. The results indicate that the vermicompost application led to a significant increase in the above-mentioned growth parameters compared to cattle manure. Foliar calcium application has a significantly positive effect on the studied properties of the plant compared to the absence of calcium. This effect was demonstrated with the application of 1.5% foliar calcium application, which gave the highest values compared to other rates (0.5 and 1.0%), which means increasing the foliar calcium application rate up to 1.5% led to enhancing the vegetative growth. Vermicompost combined with 1.5% foliar calcium application recorded the highest results of the above-mentioned measurements.

Table 5: Effect of amendments, foliar calcium application, and their interaction on some growth parameters of potato plants.

Variable		Plant height (cm)	Number of leaves.plant^{-1}	Plant fresh weight (g)	Plant dry weight (g)	Leaf area of plant^{-1}.cm2	Chlorophyll content (spade)
Amendments, A							
Vermicompost		68.2a	54.0a	562.6a	122.7a	199.0a	47.0a
Cattle manure		62.5b	51.7b	526.4b	119.5b	189.0b	44.6b
Foliar Ca Application, B							
0.0 %		58.9d	48.3d	489.2d	108.7c	178.6c	42.3c
0.5 %		63.2c	50.4c	534.6c	118.5b	184.5c	43.5c
1.0 %		67.0b	55.7b	561.6b	122.8b	198.6b	46.6b
1.5 %		72.3a	57.0a	592.5a	134.3a	214.4a	50.7a
A x B							
Vermicompost	**0.0 %**	62.4ef	49.7c	519.4f	111.6cd	182.2e	43.2c
	0.5 %	65.6cd	52.1c	533.6ef	118.6c	191.4de	44.4bc
	1.0 %	69.4b	56.1a	577.1bc	124.1b	202.4c	48.0ab
	1.5 %	75.4a	58.0a	620.5a	136.3a	220.0a	52.2a
Cattle manure	**0.0 %**	55.3g	46.9d	459.0g	105.8d	175.0e	41.4c
	0.5 %	60.8f	48.7cd	535.6ef	118.5c	177.5e	42.6c
	1.0 %	64.7de	55.2bc	546.2d	121.6bc	194.8d	45.2b
	1.5 %	69.1bc	56.0ab	564.6c	132.2ab	208.8bc	49.3a

* Control treatment is the treatment (Cattle Maure + 0.0 % of Ca)
* Similar letters indicate nonsignificant at 0.05 levels.

3.7 The effect of used organic amendments on yield

3.7.1 Physical properties of tuber yield

The results of total yield (weight and number), unmarketable tuber yield (weight and number), and tuber (Firmness and volume), in addition to the physical properties of tuber yield, are presented in **Table 6.** The results indicated that total yield per weight or number, tuber firmness and volume were significantly.

increased by using vermicompost compared to cattle manure. On the other hand, the vermicompost causes a decrease in unmarketable tuber yield in both weight and number.

Table 6: Effect of amendments, foliar calcium application, and their interaction on yield and yield quality of potato plants.

Variable		Tuber yield (Ton/acre)	Tuber number (Thousands/acre)	Unmarketable yield (Ton/acre)	Unmarketable number (Thousands/acre)	Tuber firmness	Tuber Volume (liter/ ten tubers)
Amendments, A							
Vermicompost		20.3a	179.3a	0.9b	42.3b	6.2a	4.5a
Cattle manure		13.5b	168.4b	2.5a	56.3a	6.0b	2.5b
Foliar Ca Application, B							
0.0 %		14.7d	144.5d	2.0b	54.8a	5.5c	2.9c
0.5 %		16.3c	164.6c	2.2a	55.2a	5.9c	3.2c
1.0 %		17.7b	183.0b	1.7c	45.8b	6.3b	3.7b
1.5 %		19.0a	203.2a	1.0d	41.2b	6.7a	4.3a
A x B							
Vermicompost	**0.0 %**	17.2b	144.1f	1.1b	45.6e	5.6cd	3.7de
	0.5 %	19.1b	168.2d	1.2b	52.0c	5.9c	4.1cd
	1.0 %	22.4a	193.6b	0.9b	37.6f	6.5b	4.7b
	1.5 %	22.6a	211.2a	0.6b	33.8g	6.8a	5.5a
Cattle manure	**0.0 %**	12.1d	144.9f	2.8a	64.0a	5.3d	2.0g
	0.5 %	13.5d	161.0e	3.1a	58.4b	5.8c	2.3g
	1.0 %	13.1d	172.5c	2.6ab	54.0c	6.2bc	2.6f
	1.5 %	15.4c	195.2b	1.3b	48.6d	6.6ab	3.1e

* Control treatment is the treatment (Cattle Maure + 0.0 % of Ca)
* Similar letters indicate nonsignificant at 0.05 levels.

Foliar calcium application at 1.5% gave significantly higher values in the above-mentioned properties, except for the potato's unmarketable yield weight or number, which were decreased. The application of vermicompost at a rate of 20 m^3/acre in conjunction with a foliar calcium application at a concentration of 1.5% resulted in a notable increase in yield characteristics, including tuber total weight, number per plot, tuber firmness, and volume.

3.7.2 Chemical properties of tubers and leaves:

The effect of vermicompost and foliar calcium application on the percentage of tuber starch, total carbohydrates and the contents of nutrient availability (N, P, K) in the dry leaves are shown in **Table 7**

The obtained results were in line with the previous measurements, where using vermicompost combined with 1.5% of calcium application resulted in a significant increase in all the above-mentioned chemical properties of tuber yield, while using cattle manure combined with 1.5% of calcium application was significant for the P and K contents in the leaf comparing with control.

Table 7: Effect of amendments, foliar calcium application, and their interaction on some chemical properties of potato plant leaves and tubers.

Variable		Starch (%)	Total carbohydrates (%)	Elements content of leaves		
				Nitrogen	Phosphorus	Potassium
Amendments, A						
Vermicompost		89.4a	80.7a	4.21a	0.332a	5.31a
Cattle manure		74.2b	72.6b	3.26b	0.301b	4.81b
Foliar Ca Application, B						
0.0 %		76.0c	71.2c	3.28c	0.282c	4.51b
0.5 %		80.5b	74.9c	3.62b	0.293c	4.84b
1.0 %		83.3b	78.5b	3.85b	0.329b	5.24b
1.5 %		87.4a	82.2a	4.20a	0.360a	5.64a
A x B						
Vermicompost	**0.0 %**	82.3c	74.5c	3.77cd	0.303b	4.81c
	0.5 %	86.6c	77.5c	4.00b	0.305b	5.05b
	1.0 %	91.5b	82.8b	4.49ab	0.347a	5.55ab
	1.5 %	97.3a	88.1a	4.60a	0.372a	5.81a
Cattle manure	**0.0 %**	69.8e	67.8e	2.80e	0.262c	4.21d
	0.5 %	74.4de	72.2d	3.24d	0.282c	4.63c
	1.0 %	75.2d	74.1cd	3.22d	0.311b	4.93bc
	1.5 %	77.5d	76.2c	3.80c	0.348a	5.46a

* Control treatment is the treatment (Cattle Maure + 0.0 % of Ca)
* Similar letters indicate nonsignificant at 0.05 levels.

4. DISCUSSION:

4.1 Chemical analysis and microbial count of used organic amendments

The obtained results reveal that vermicomposting promoted further decomposition and changed microbial communities compared to results of cattle manure, which was an ingredient used to prepare vermicompost. Data indicate that vermicomposting reduced C/N ratio compared to cattle manure, confirming the abundance of nitrogen in the produced vermicompost, which agrees with the findings of **Hoque, *et al.* (2022). Fernando and Arunakumara (2021**) found that vermicompost is rich in N, P, soluble K, and exchangeable Ca. Additionally, its fine texture increases the surface area, providing more microhabitats for beneficial bacteria, fungi, and actinomycetes.

4.2 Soil microbial count, soil carbon mineralization and the cumulative gas emission fluxes

The respiratory activity of soil microbial communities based on CO_2 efflux evolution (mg/g/d) revealed distinct differences as affected by the used treatments after one and two months of cultivation, and these differences evolved over time. The most important results in soil microbial count are recording of relatively high value of TFC and the significantly highest TBC by applying vermicompost +1.5% Ca, and at the same time recording the lowest value of TSC after one and two months of cultivation. That could mean that this treatment enhanced ventilation, beneficial microbial activities, at the same time reduced spoilage organisms and pathogenic bacteria, as illustrated by **Doyle, *et al.* (2015)**. This observation is consistent with the findings of **Pathma and Sakthivel (2012**), who stressed the complex relationship between earthworms and microorganisms. Their study revealed that earthworms can increase the population of soil microorganisms by as much as fivefold by consuming plant growth-promoting rhizospheric bacteria along with the surrounding rhizospheric soil. The digestive system of earthworms may promote the activation or growth of these beneficial bacteria. These beneficial bacteria is essential for improving the biological characteristics of soil, particularly in their ability to inhibit pathogens, especially fungi.

Other than the vermicompost treatment without calcium spraying, all treatments decreased CO_2 efflux after two months, compared with results after one month of cultivation. The highest reduction was found with the treatment of vermicompost +1.5% Ca, where it gave the lowest value of CGEF (19.4 mg-g-1) The enhanced microbial communities significantly increased the decomposition of organic matter and CO_2 emissions, but in turn, increased soil organic carbon (SOC), where, as more SOC is formed, less CO_2 will be emitted into the surrounding atmosphere (**Kuzyakos, 2006 and Watts, *et al.*, 2011**). **Zhou *et al.* (2017b**) indicated that the use of cattle manure as an organic fertilizer on agricultural lands is a longstanding practice that enhances crop productivity, increases soil fertility, and contributes to the augmentation of soil organic carbon reserves. The components used in the preparation of vermicompost determine the amount of emissions released, for instance, **Zeng, *et al.* (2023)** found that the N_2O emission from sludge-prepared vermicompost was 14.5 times higher than that of cattle dung-prepared vermicompost. The reduction or increase of emissions is controlled by the operation or inhibition of different sets of microbial genes, as illustrated by **Gong, *et al.* (2023).** The application of organic fertilizers such as vermicompost in paddy soil has not only enhanced rice production but has also resulted in a significant increase in CO_2 sequestration by 155-181%, respectively, compared to the use of inorganic fertilizers **(Haque, *et al.*, 2020),** Soil respiration, measured as soil CO, efflux, significantly influences the general equilibrium of soil organic matter (**Bell, *et al.*, 2023).** On the other hand, **Shabtai, *et al* (2023**) reported that adding calcium to the soil changed the community of microbes present in the soil and the way they behaved. Using calcium makes microbes more efficient in stabilizing soil-borne carbon into organic matter, resulting in more carbon retained in the soil and less lost to the atmosphere as CO_2. That may explain the recorded highest value of total bacterial count and the relatively high total fungi by applying vermicompost with 1.5% calcium nitrate, and, at the same time, there was a relatively high decrease in CGEF.

4.3. Soil organic matter content

Obtained data refers to a significant increase in SOM with the addition of vermicompost compared to cattle manure, particularly during the second season. This finding could be attributed to vermicompost's fine texture, which creates a large surface area, providing numerous microhabitats for beneficial bacteria, fungi, and actinomycetes to thrive. Vermicompost can enhance soil microbial activity by introducing additional microorganisms, providing nutrients as a food source, and increasing the surface area available for microbial growth. This fosters decomposition, improves soil biological properties and enhances organic matter content, including humic substances, which contribute to the soil's self-renewal capacity (**Sinha, *et al.*, 2009 & Fernando and Arunakumara, 2021**).

4.4. The presence of nitrogen (N), phosphorus (P), and potassium (K) within the soil profile.

The recorded increment in the studied nutrient availability could be demonstrated by **Sinha, *et al* (2009),** who reported that vermicompost contains humus, macronutrients, micronutrients and various enzymes that remain active in the decomposition of organic matter in the soil, thereby improving the availability of nutrients in the soil. They added that, the continuous applying of vermicompost makes the net overall efficiency of nitrogen over the years is considerably greater than 50% of that of chemical fertilizers, and a much greater availability of phosphorus too, which mean that continuous application of vermicompost can greatly decrease the demand of nitrogen chemical fertilizers which reached approximately 112 million tons by 2022 according to **FAO, (2019)** by about 50%. **Mahmud, *et al.* (2018**) demonstrated that soils enhanced with vermicompost exhibit a greater total nitrogen content compared to those treated with chemical fertilizers, as assessed six months post-planting.

The obtained enhancement in (P) levels in soil with the treatment of vermicompost could be explained also by the solubilizing action of organic phosphorus, which inhibits the fixation of P by chelating P-fixing cations. Furthermore, research indicates that vermicompost significantly influences soil microbial biomass and enhancing P dynamics in the soil and facilitating the phosphorus cycling process (**Singh, *et al.*, 2015**). **Raza, *et al.* (2022**) emphasized that vermicompost releases chemicals that cause phosphate solubilization. Vermicompost can also replenish the soil with K, which is depleted by time not only by crops but also by being fixed by clay minerals in a large amount to become slow to be released by the available microbial activities (**Abdul Wakeel, *et al.*, 2013**). **Shaban, *et al.*, (2019**) who concluded that the application of calcium sources at a high rate which drop down at the soil surface and penetrate the first soil sector, could be used to improve soil properties and increase the available nutrients.

4.5. Available calcium in the different soil profiles

The increment that occurred in the available calcium in the soil at the 0-20 cm layer can be related to absorbing calcium through foliar application followed by the solution dripping onto the soil surface, where it infiltrates at the upper layer of the soil. On the other hand, sufficient organic matter allows the decomposition of organic matter within the soil sectors and a variety of biological processes that increase the availability of organic acids and various elements, especially calcium, as mentioned by **Ahmad, *et al.* (2011**). Data demonstrated that vermicompost enriched the quantity of soluble calcium in both soil profile depths compared to the cattle manure. This may be due to the high Ca content in vermicompost, according to **Fernando and Arunakumara (2021**).

4.6 The effect of used organic amendments and foliar calcium application on some growth parameters

The significant increase in growth parameters when vermicompost application was used may be considered a result of the significant increase in the above-mentioned physical and chemical properties of plants. This could be explained by the increase in cell division and enlargement ascribed to an improvement in subsequent uptake of nutrients. These results agreed with **Sinha, *et al.* (2009**), who described vermicompost as a miracle growth promoter and protector. They confirmed that vermicompost supplies balanced nutrients to plant roots, stimulates growth and also increases the organic matter content of the soil, including humic substances that promote growth.

Hoque, *et al.* (2022) asserted that vermicompost increased crop performance under field conditions. In this study, using foliar calcium application of 1.5% gave the highest values of vegetative parameters. This finding agrees with that found by **El-Morsy, *et al.* (2020),** who indicated that foliar spray up to 2000 ppm led to significant increases in most vegetative growth characteristics of potato. The interpretation of these results may be because calcium is crucial for various important functions in plants related to the uptake of nutrients, facilitates the growth of primary roots, supports appropriate cell elongation, strengthens cell walls and plays a role in enzymatic and hormonal activities (**Shaban, *et al.*, 2019**).

4.7 The effect of used organic amendments and foliar calcium application on yield:

4.7.1 Physical properties of tuber yield

The use of vermicompost at a rate of 20 m3 per acre, in conjunction with a foliar calcium application at a concentration of 1.5%, resulted in significantly enhanced yield characteristics. This obtained positive results can be illustrated by the findings of **Mahmud, *et al.* (2018**) who reported that vermicompost can preserve nutrients for prolonged durations, demonstrates a remarkable ability to retain water, and possesses higher porosity compared to conventional compost, a characteristic linked to its humus content. **Sinha, *et al.* (2009)** demonstrated that the application of vermicompost as an organic amendment positively affects seed germination, enhances the growth rate of seedlings, and promotes flowering and fruiting in various flowering plants and significant crops, including potatoes. **Hoque, *et al.* (2022)** found that using mineral fertilizer with the application of vermicompost increased the grain yield of Boro rice by 25% compared to the control treatment. **El-Hadidi, *et al.* (2017**) mentioned that the tubers yield and the average weight of the tubers were improved with foliar calcium application. Furthermore, **El-Morsy, *et al.* (2020)** treated plants with foliar calcium spray at different concentrations, the overall yield of potato tubers, as well as the yield of marketable tubers showed a significant enhancement and the most pronounced effects noted at the maximum concentration of 2000 ppm.

4.7.2 Chemical properties of tubers and leaves:

The clear results that refer to a significant increase of all measured chemical properties of tubers and leaves with the treatment of vermicompost agree with that concluded by **Mahmud, *et al.* (2018)** where they found that vermicompost improves the nutrient content of different plant components compared to conventional compost due to it includes a wide range of essential nutrients, including N, P, K, Mg, Ca, S, Fe, B, Cu, Zn, and Mn. This may be illustrated by the findings of **Fernando and Arunakumara (2021**), who mentioned that the application of vermicompost could increase plant nutrient uptake efficiency. This result was supported by **Raza, *et al.* (2022**) who emphasized that vermicompost releases siderophore production, Phytohormones and hormones that influence plant metabolism and regulate ionic absorption.

The significantly higher values of the mentioned chemical properties after foliar application of 1.5% calcium aligns with the findings of **El-Hadidi, *et al.* (2017)** who used the foliar calcium nitrate at concentrations of up to 0.8%, which led to a notable increase in the levels of chlorophyll, starch, and various macroelements in potato leaves when compared to the control.

Additionally, **El-Morsy, *et al.* (2020)** noted an increase in tuber content of (N, P, K) and starch with increasing calcium levels up to 2000 ppm. This result may be attributed to foliar calcium application, which could enhance mineral uptake and translocation in different plant parts (**Refaie, 2018).**

5. CONCLUSION:

In this study, vermicomposting has proven its efficiency in converting organic waste materials into a valuable organic amendment, helping in the mitigation of CO_2 emissions through sequestration of the organic carbon into the soil and plants. Vermicompost uplifted soil biological and chemical properties and helped to maintain soil health, likewise increased the organic soil matter content, which is usually depleted by unsustainable practices. Furthermore, it has beneficial effects on improving crop yields and enhancing the physical and chemical characteristics of potatoes, surpassing those of cattle manure. The study paid more attention to the importance of using Ca and its suitable rates. It could enhance the values of potato quality parameters significantly, where foliar application of Ca improves potato growth and achieves a higher tuber yield with the highest quality when it is used at the rate of 1.5%. Using vermicomposting at a rate of 20 m^3/acre combined with calcium foliar application at the rate of 1.5% produced potato plants with excellent growth performance in high linearity with environmental sustainability under the studied conditions.

This investigation is sharing in scientific efforts creating awareness about the importance of becoming more sustainable through environmentally friendly farming practices, such as vermicompost and Ca spraying, which can improve crop production in parallel with achieving sustainability goals, such as mitigating the effects of climate change.

Consent for publication

The article contains no such material that may be unlawful, defamatory, or which would, if published, in any way whatsoever, violate the terms and conditions as laid down in the agreement.

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