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Phosphorus Sources and Sheep Manure Fertilization for Soil Properties Enhancement and Sugar Beet Yield

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Abstract

Inorganic fertilizers abundant used cause hazardous environmental effects and unsafe food. Contrarily, organic fertilizers are usually utilized as soil amendments and they boost crop yield quantity and quality. A field experiment was carried out to study the effect of some phosphorus (P) sources, such as rock phosphate (RP), superphosphate (SP), and sheep manure (SM), on some soil chemical properties, growth and yield in sugar beet plants. The field experiment was arranged in a completely randomized block design with three replicates for two growing seasons (2020/21and 2021/22). Results showed significant increases in yield and physiological parameters in all treatments. Co-applying of RP with SP caused a significant increase in the SOM, N, P, and K by 70.45, 31.52, 128.35, and 24.85% respectively compared to T1. All applications to the soil significantly increased the fresh weights of sugar beet roots were significantly increased by 24.71, 17.92 and 25.72% for T2, T3, and T4 respectively over the control. Also co-application of SM and SP (T3) lead to the highest sucrose content which increased by 5.09% than the control. Therefore, we concluded that integrated fertilizer management improves soil properties and yield so these results can be used to employ to reduce the detrimental consequences of using chemical fertilizers.

Keywords Rock phosphate · Super phosphate · Sugar beet · Sheep manure

Introduction

Agricultural systems are currently aiming to maximize and maintain agricultural production the nutrient shortage is one of the key challenges in the development of economically effective agriculture. So using adequate rates and sources of natural organic fertilizers is very important not only to increase yield but also to reduce the production cost and environmental pollution (Ali et al. 2021; EL-Sharnoby 2021).

Phosphorus is an essential macronutrient required for the growth of plants alongside nitrogen and the addition of phosphate fertilizers is also important in ensuring the world's food production (Torri et al. 2017). The productivity of crops is impacted by the deficiency of phosphorus, which affects more than 40% of the world's arable land (Zhu et al. 2018; Victor Roch et al. 2019). In recent years, to ensure high crop yields, phosphorus-containing fertilizers have been widely used to counteract soil deficiency (Teng et al. 2020). This deficiency is a significant contributing factor to the poor fertile soil.

On the other hand, phosphorus also shows an essential biochemical task in cell division, energy storage, respiration, photosynthesis, transfer, growth and many other processes in plants. It can help plant to live winter rigidities and contributes to disease resistance (Yadav and Pandey 2018; Khan et al. 2019).

Sheep manure (SM) is a nutrient rich organic carbon that can be used as a soil amendment to serve as a partial replacement for chemical fertilizers in agricultural production. Moreover, the addition of organic manure to soil can prominently improves physical and chemical properties, nutrient availability, microbial activity, increase yield, and enhance growth parameters (Paramesh et al. 2022). Moreover, organic fertilizers have fragmentize pattern with too much porosity, which helps great aeration and water retention capacity, and contain great nutrient amounts in available form

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for plant adsorption nitrogen, phosphorus, potassium, calcium, and magnesium etc (Chew et al. 2019; Ali et al. 2021; Al-Sayed et al. 2022; Güneş et al. 2023). Additionally, soil organic matter enhances the hold of nutrients, like N, P and S into its structure that mostly included C (55%), N (5–6%), P (1%) and S (1%) and these nutrients are released slowly and mostly taken up by plants (Al-Sayed et al. 2019; Ali et al. 2021). Farmyard manure (FYM) application caused significant yield increments during the 2016 to 2018 growth season. The average sugar beet yield was 52.9 tons ha^{-1} without FYM application and 61.2 tons ha^{-1} with FYM application.

For decades, chemical fertilizers have been utilized to enhance crop productivity (Hafez et al. 2021). Also, with the huge costs of chemical fertilizers, environmental pollution, and soil degradation, presently agriculture tends to reduce the use of these fertilizers (Al-Sayed et al. 2019 and Ali et al. 2022). Moreover, adding alone fertilizers containing phosphorus will deplete micro and secondary nutrients such as Zn, B, and S (Elias et al. 2019). To reduce the use of chemical inputs and maintain or increase soil fertility and plant nutrition, the use of organic fertilizers in modern agriculture is an option that is safe. Uprising prices of mineral fertilizers and the urge need of organic farming for sugar beet production attract the attention of organic market to add manures to sugar beet crop (Hlisnikovský et al. 2021). Moreover, the proportion of chemical fertilizer substitution should be carefully studied.

Rock phosphate (RP) is a natural mineral that contains high quantities of phosphate-bearing minerals and is classified as a non-renewable resource (Moussa et al. 2016). Also, RP is the basic raw material for makings soluble phosphate fertilizers (Saied et al. 2022). Agricultural intensification in developing countries with high reserves of rock phosphate can contribute as a source of phosphorus in the right way (El-Kherbawy et al. 2014). The production of 97% of the world's phosphate ore is concentrated in 16 countries, with each country generating millions of tons annually (Abdelgalil et al. 2022). Moreover, adding organic matter to soil can increases available phosphorus, which supplies available P in rock phosphatefor plants. Rock phosphate solubilization might enhance the nutritional value of the plants (Maharana et al. 2021). The most important parameters which point to the overall changes in the soil chemical characteristics are soil reaction (pH). Soil reaction helps in preserving soil fertility and to keep equilibrium among soil nutrients (El-Sayed 2021).

Co-application of alternative sources for P and inorganic fertilizers is a promising way to stabilize crop yields, increase nutrients in the soil, and alleviate environmental degradation to get healthy food.

Sugar beet (*Beta vulgaris* L.) is the main crop for sugar production in many countries. It ranks as the second most remarkable crop in the world after sugarcane for sucrose production. The cultivated area of sugar beet crop in Egypt through the 2018/19 season was ≈255,725.6 ha (increased by 23.5% over the 2017/18 season), that produce ≈12,247,170 tons of sugar (62.2% of national sugar production), with an average root yield of 47.89 ton ha-1 (Ministry of Agriculture and Land Reclamation 2019). Nowadays, sugar production from sugar beet has reached 1.27 million tons which is about 58% of the total sugar production. The regional sugar industry relies on sugar beet since it occupies ≈14,700 hectares, 0.7% of the total cultivated area, (Rehab et al. 2019; Sugar Crops Council 2020). Nutrient management is essential for early sugar beet production. Insufficient nutrient and late fertilizer applications might cause irreversible root and sucrose yield reductions. Moreover, used fertilizer application is negatively correlated with sugar beet quality especially nitrogen (Hergert 2011; Van Eerd et al. 2012). The objectives of this study were to: (1) investigate the effects of different combinations of P fertilizer and rates on soil properties, growth plant, and yield of sugar beet. (2) Determine a better P management strategy for winter sugar beet yield, partial substitution of chemical fertilizer by the organic alone or with natural fertilizers phosphates. We hypothesized that co-application of RP fertilizer and SP under sheep manure maybe improve crop productivity and reduce the amount of inorganic P fertilizer.

Materials and Methods

Site Experiment and Design

A field trail was carried out during 2020/21 and 2021/22 growing seasons at the Agriculture Research Center Farm, Faculty of Agricultural, Al-Azhar University, Assiut Governorate, Egypt (27° 12′16.67″ N latitude and 31° 09′ 36.86″ E longitude). The experimental site's climate was brought from Assiut Agrometeorological station, Assiut, Egypt, and is depicted in Table 1. Some physiochemical properties of the experimental site are listed in Table 2, while Table 3 show some chemical properties of tested materials.

The Agricultural Research Centre, Giza, Egypt was the source of sugar beet seeds (BTS 645. cv), and they were sown in the field at 22nd of August in each season. The experimental treatments were arranged in a completely randomized block design with three replicates with a total number of 12 plots, in each replicated three rows 70 cm apart with three hills. Sugar beet seeds were hand planted on hills in 5–10 cm depth with 25 cm apart (plants density 64260 ha^{-1}). The unit of experiment was 3 m width × 3.5 m length (10.5 m^2). The seedlings were thinned to one plant

Table 1 Basic climatic data of the experimental site during the period of the study (August to March 2020/21 and 2021/22). Based on Assiut agro meteorological station, Assiut, Egypt

	T_{max} (°C)		T_{min} (°C)		R H (%)		W S (Kmh-1)		Sunshine	
	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season	1st season	2nd season
August	38.4	39.10	24	24.20	38.5	28.10	17.1	14.50	11.9	11.90
September	37.8	35.20	23.2	21.40	41.1	39.50	17.8	18.10	10.8	10.80
October	34.6	32.40	20.5	17.60	47.8	44.20	17.1	14.90	10	10.00
November	25.3	28.60	12.7	13.40	55	50.70	14.9	9.90	9.4	9.40
December	23.60	20.30	9.40	7.70	53.60	54.70	14.30	10.70	9.00	9.00
January	21.4	16.88	7.1	4.47	58.9	35.90	13.5	17.10	8.9	8.87
February	21.6	21.22	7.3	8.07	57.4	51.18	15.9	15.17	9.7	9.70
March	27.1	22.25	11.3	8.03	43.4	41.65	18.6	17.33	9.9	9.87

Tmax maximum temperature (°C), *Tmin* minimum temperature (°C), *RH* relative humidity (%), *W.S* wind speed (km/h)

Table 2 Some physiochemical properties of the experimental site

Property	First season	Second season
pH (1:2.5 soil: water suspension)	8.22	8.24
EC_e (dS m^{-1})	1.28	1.25
Organic matter (g kg^{-1})	10.00	10.50
Sand (g kg^{-1})	254	252
Silt (g kg^{-1})	392	393
Clay (g kg^{-1})	354	355
Texture	Clay loam	Clay loam
$CaCO_3$ (%)	3.60	3.91
Available N (mg kg^{-1})	27.00	30.00
Available Olsen P (mg kg^{-1})	5.32	5.89
Available K (mg kg^{-1})	192	212

Table 3 Some chemical properties of tested materials

Characteristic	Sheep manure	Rock phosphate
Total-N (g kg^{-1})	8.40	–
Total-P (g kg^{-1})	12.00	170.00
Total-K (g kg^{-1})	32.40	–
OM (g kg^{-1})	395.00	–
pH (1:5)	8.41	7.69
EC (1:5) dsm^{-1}	5.16	4.09

per hole after 20 days of sowing (DAS). According to the Egyptian Ministry of Agriculture and Land Reclamation, 71.40 kg P ha^{-1} from either rock phosphate (17% P_2O_5) or super-phosphate (15.5% P_2O_5) were applied to each plot alone or from both sources during soil preparation. Total 190.40 kg N ha^{-1} comes from two sources; 95.20 kg N ha^{-1} from sheep manure (0.8% N) as organic source was added through soil preparation and the other 95.20 kg N ha^{-1} from urea fertilizer (46% N) as chemical source was split into two uniform doses which applied at 30 and 90 days after sowing. Total 57.12 kg K ha^{-1} in form of potassium sulfate (K_2O_5) was divided into two equal doses; the 1st was added through soil preparation and the 2nd dose was added at 30 DAS. The tested treatments were as follows:

1. The suggested amount of chemical fertilizers (N, P and K), as control treatment (T1).
2. 71.40 kg P ha^{-1} from rock phosphate (RP) (T2).
3. 71.40 kg P ha^{-1} from superphosphate (SP) (T3).
4. 35.70 kg P ha^{-1} from superphosphate (SP) + 35.70 kg P ha^{-1} from rock phosphate (RP) (T4).

At harvest, sugar beet roots and plant samples were gathered on 9th and 3rd of March 2021 and 2022, (after 199 and 195 days from sowing) respectively. Five randomly selected plants' roots were taken at mid plot were collected to record the fresh weight, to estimate yield components and some quality traits (TSS% and Sucrose %). The fresh roots were washed with tap and distilled water, air dried, and oven dried at 70 °C until constant weight then dry yield was recorded, and picked random roots to be ground and stored for chemical analysis (N, P and K uptake).

Plant and Soil and Analysis

Soil texture was measured using pipette method and soil reaction (pH) was determined as described by (Page et al. 1982). Soil salinity and calcium carbonate were determined according to Burt (2004). Available P was extracted with 0.5 N $NaHCO_3$ and measured spectrophotometery at 660 nm wavelength (Olsen et al. 1954). Available K was measured by the flame photometer (Jackson 1973). Available N was extracted by 1% K_2SO_4 at a ratio of 1:5. Then, 20 ml of the extract were distilled with the addition of 1 g Devarda's alloy using a micro Kjeldahl's (Jackson 1973). Soil organic matter (SOM) content was determined by oxidization with $K_2Cr_2O_7$ and H_2SO_4 (Jackson 1973). The total N, P and K concentrations were measured in the digest extract. To measure the concentrations of these nutrients in beet roots, a mixture of 7:3 ratio of sulfuric to perchloric acids was used to digest the dried ground plant material (0.2 g). Total N, P and K were determined according to Burt (2004). Chlorophyll contents from fully developed leaves were measured by spectrophotometer at 663 and 644 nm for Chl-A and Chl-B, respectively; the blank was 95% ethyl alcohol that measured by the modified protocol of (Lichtenthaler 1987) using the following formulas:

$$\text{Chl.(A)} = (13.36 * \text{A663}) - (5.19 * \text{A644}).$$
$$\text{Chl.(B)} = (27.49 * \text{B644}) - (8.12 * \text{A663}).$$

Quality Traits

1. In juice of fresh root, total soluble solids percentage (TSS %) was measured using hand refract meter.
2. Sucrose percentage (%) was determined according to Le Docte (1927).
3. Juice purity percentage (%) was calculated according to the following equation:

$$\textbf{Juice purity}\,\% = \frac{\textbf{Sucrose}\,\%}{\textbf{TSS}\%}\textbf{x100}$$

Statistical Analyses

Analysis of Variance and Duncan multiple range tests at 5% level of probability were used to examine significant differences among the treatments at seasons of 2020/21 and 2021/22. Data statistical analyses were performed using Costat software (Steel and Torrie 1986).

Results

Some Soil Chemical Characteristics

Application of sheep manure (SM) combined with rock phosphate (RP) and or super phosphate (SP) during both seasons realized positive and significant effects on decreased soil reaction (pH). The soil pH was moderately alkaline through all treatments and both seasons. Compared to control treatment, the added materials resulted in a significant rise in soil organic matter content (SOM) in both seasons. In contrast, the added materials adversely affected soil salinity (EC) compared to the untreated soil (Table 4). It was noticed that combined both P sources positively increased SOM and decreased soil pH while negatively increased soil salinity compared to other treatments. As average values of both seasons, the increases in soil salinity values were 8.33, 5.30 and 39.39% for T2, T3 and T4, respectively compared to T1 (control). Also the increases of SOM values were 47.26, 64.81 and 70.45% for T2, T3 and T4, respectively compared to T1.

Nutrients Availability

Sheep manure applications combined with RP and SP throughout both seasons significantly ($P<0.05$) increased N, P, and K availability (Table 5). In seasons, combined SM, RP, and SP (T4) significantly enhanced P availability compared to the other treatments. As average values of both seasons, available N increased by 37.12, 50.93 and 31.52% for T2, T3 and T4, respectively compared to control treatment (T1). Also, available P increased by 42.49, 75.82 and 128.35%, where available K increased by 24.83, 42.40 and 24.85% for T2, T3 and T4, respectively compared to T1.

Table 4 Influence of adding sheep manure and phosphorus sources on some soil chemical properties

Treatment	pH (1:2.5)		EC (1:1 dSm^{-1})		OM ($g\,kg^{-1}$)	
	1st	2nd	1st	2nd	1st	2nd
T1	8.24a	8.23a	1.30b	1.34b	12.60b	12.23c
T2	8.16b	8.15b	1.48b	1.38b	18.54a	18.04b
T3	8.14c	8.13c	1.44b	1.34b	19.46a	21.47a
T4	8.12d	8.11d	1.89a	1.79a	21.58a	20.75a

Means denoted by the same letter indicate insignificant difference according to Duncan's test at $p<0.05$

Table 5 The effect of adding sheep manure and phosphorus sources on nutrients availability during both seasons

Treatment	N ($mg\ kg^{-1}$)		P ($mg\ kg^{-1}$)		K ($mg\ kg^{-1}$)	
	1st	2nd	1st	2nd	1st	2nd
T1	51.44c	70.00c	6.98c	7.49c	226.60d	224.71b
T2	73.09a	92.29ab	9.73c	10.91b	259.94c	303.23a
T3	79.67a	102.67a	13.24b	12.14b	317.44b	325.17a
T4	70.00ab	88.67b	16.45a	16.57a	341.97a	321.15a

Means denoted by the same letter indicate insignificant difference according to Duncan's test at $p<0.05$

Macronutrients Uptake by Sugar Beet Roots

Adding SM mixture with RP or SP considerably impacted NPK uptake by sugar beet roots in both seasons (Fig. 1). Applying SM with RP (T2) achieved the highest N and P uptake by sugar beet roots since they increased by 78.44 and 46.60%, respectively, while (T4) achieved the highest K uptake since it increased by 65.03% over the control treatment. While the lowest nutrients uptake was observed at T4 (50/50 of both P sources mixed with sheep manure). During both growing seasons, the N and P uptake by sugar beet roots followed the order *of T2 > T3 > T4 > T1* (Fig. 1).

Sugar Beet Yield

Fresh and dry weight of sugar beet yield as affected by adding sheep manure with various phosphorus sources are shown in Table 6. Adding sheep manure mixed with rock phosphate (RP), superphosphate (SP), or both had a significant ($p < 0.05$) influence on total fresh and dry root yield weight in both seasons (2021–2022) compared to chemical fertilizers (T1). It was noticed that sugar beet yields are higher in the 2nd season than those of the 1st season. As average values of both seasons, the fresh weights of sugar beet roots were 64.92, 80.97, 76.56 and 81.64 ton ha^{-1} for T1, T2, T3, and T4, respectively. So, the relative increased of fresh weights of sugar beet roots were 24.71, 17.92 and 25.72% for T2, T3 and T4, respectively compared to control treatment (T1). The dry weights of sugar beet roots were 16.41, 19.04, 18.51 and 19.29 ton ha^{-1} for T1, T2, T3, and T4, respectively. The dry weights of sugar beet roots increased by 15.99, 12.83 and 17.55% for T2, T3 and T4, respectively compared to T1.

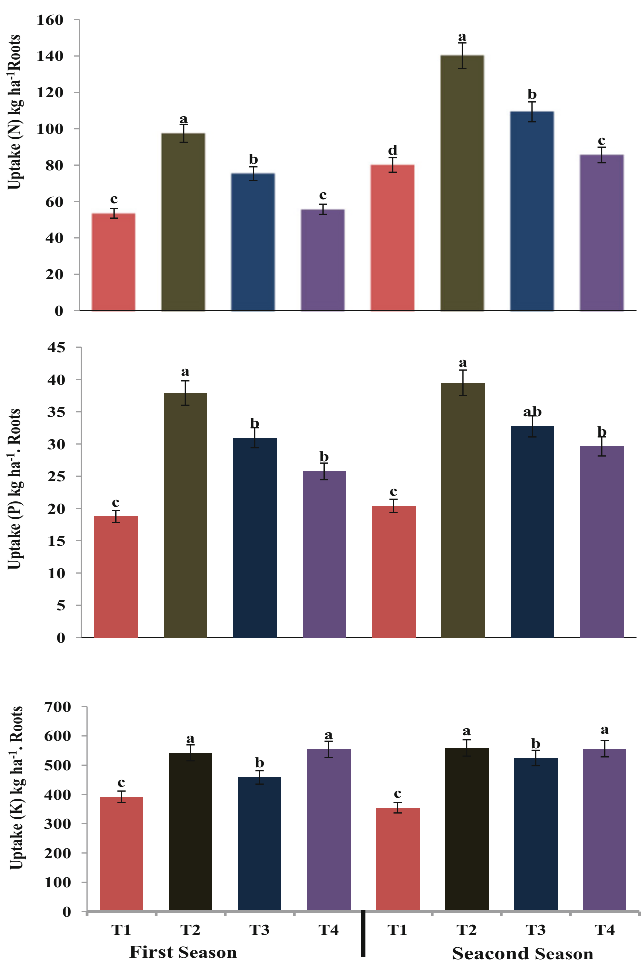

Fig. 1 Effect of adding sheep manure and varies phosphorus sources on nutrients uptake during both seasons. Means denoted by the same letter indicate no significant difference according to Duncan tests at $p < 0.05$

Table 6 Effect of adding sheep manure and phosphorus sources on fresh and dry weight of sugar beet roots

Treatment	Fresh weight (t ha^{-1})		Dry weight (t ha^{-1})	
	1st	2nd	1st	2nd
T1	64.05b	65.79c	16.27b	16.54b
T2	79.43a	82.50ab	18.62a	19.45a
T3	75.16a	77.95b	18.42a	18.60a
T4	78.17a	85.11a	19.26a	19.31a

Means denoted by the same letter indicate insignificant difference according to Duncan's test at $p < 0.05$

Leaf Total Chlorophyll

At mid-season of sugar beet plants, the levels of chlorophyll (a) and (b) in leaves were higher in the 2nd season than those in the 1st season (Fig. 2). During both seasons, the highest chlorophyll (a) and (b) values were obtained When SM was combined with SP (T3) and RP + SP (T4), which increased chlorophyll (a) and (b) by 12.72 and 32.68%, respectively (T3), while, the treatment (RP + SP (T4) increased chlorophyll (a) and (b) by 16.81 and 40.68%, respectively. The levels of chlorophyll (a) and (b) of sugar beet leaves could be arranged in descending order of T4 > T3 > T2 > T1.

Sugar Beet Quality

The impact of applying sheep manure and various phosphorus sources on the sucrose content, total soluble solid (TSS), and purity percentage of sugar beet roots are shown in (Fig. 3). All treatments led to an increase in total soluble solid (TSS) compared to the control treatment (T1) with insignificant differences. However, Applying SM mixed with SP (T3) achieved the highest sucrose content by 5.09%, followed by SM combined with RP (T2) by 2.37%, SM mixed with SP + RP (T4) by 1.18%, and the latest one was

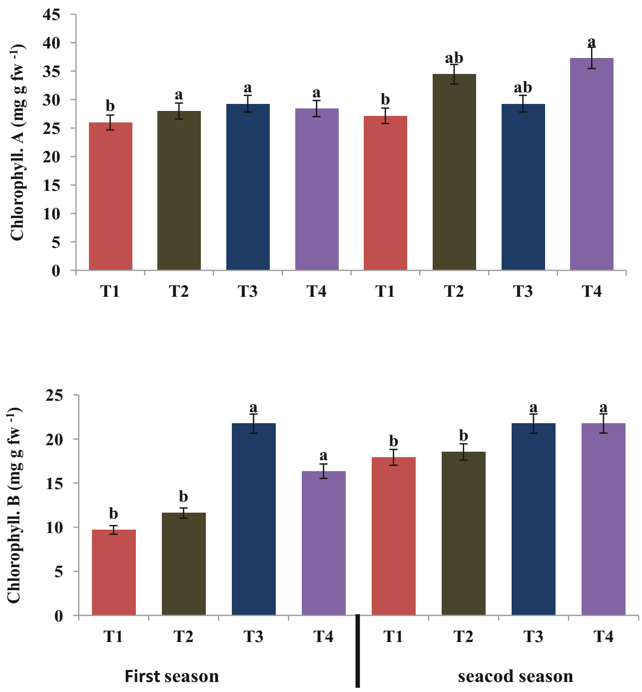

Fig. 2 Effect of adding sheep manure and varies phosphorus sources on some photosynthesis pigments. Means denoted by the same letter indicate no significant difference according to Duncan tests at $p<0.05$

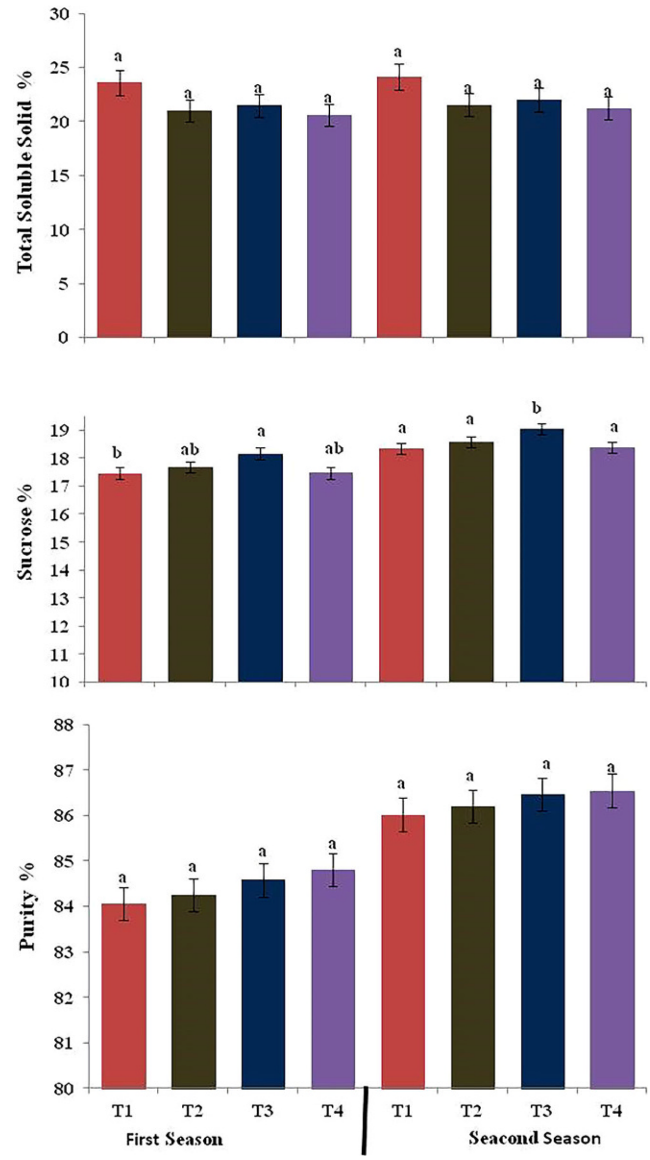

Fig. 3 Effect of adding sheep manure and varies phosphorus sources on some sugar beet quality parameters. Means denoted by the same letter indicate no significant difference according to Duncan tests at $p<0.05$

the control treatment (T1). There were insignificant changes in purity percent between applying sheep manure combined with various phosphorus sources and the control treatment. On the other hand, the purity percent followed the descending order of T4 > T3 > T2 > T1.

Relationship Between Soil Properties and Sugar Beet Yield

The impact of applying sheep manure combined with various phosphorus sources on soil properties, nutrient availability and sugar beet yield were evaluated by principal component analysis, PCA, (Table 7 and Fig. 4). The first four axes are significant for both seasons, with component weights of 91.03 and 90.39%, respectively, of the total variance. In the first season, with a 50% variance, the PC1 explained the variation in N, P, and K uptake (0.716, 0.891, and 0.819, respectively), yield (0.808), and dry weight (0.717), demonstrating the significant contribution of the application of sheep manure combined with various phosphorus sources to sugar beet productivity. The 2nd PC (68.02% CV) showed that OM (0.731), Av. P (0.918), Chl. B (0.974), and Chl. A (0.634) had substantial positive loading strength, revealing a strong connection between Av. P, OM, Chl. B, and Chl. A. It is also apparent that OM and Av. P play the most important roles in sugar beet productivity. The 3rd PC (80.73% CV) described available N and K (0.694 and 0.823), sucrose content (0.918) and total soluble solid (0.772), indicating the importance of sheep manure application in increasing available N and K. The PC4 (91.03% CV) revealed that there is a negative relation between purity (0.988) and TSS (–0.587). However, in the second season, PC1 explained 56.25% of the variance in OM (0.754), Av. P (0.919), Chl. A (0.775), Chl. B (0.913), and yield (0.609). The second PC (70.91% CV) revealed N, P, and K uptake (0.873, 0.915, and 0.802, respectively), as well as Av. K (0.620), yield (0.648), and dry weight (0.643). The 3rd PC (80.73% CV) described available N (0.548), sucrose content (0.792) and total soluble solid (0.912). According to the PC4 (90.39% CV),

Table 7 Principal components and their loading in soil treated with sheep manure combined with various phosphorus sources, affect nutrient availability and sugar beet productivity through both seasons

Parameters	First season				Second season			
	1	2	3	4	1	2	3	4
OM	0.534	0.731	0.190	0.114	0.754	0.481	0.379	0.027
Av. N	0.535	0.445	0.694	–0.005	0.517	0.536	0.548	–0.104
Av. P	0.184	0.918	0.101	0.113	0.919	0.257	–0.148	0.111
Av. K	0.189	0.246	0.823	–0.015	0.613	0.620	0.264	0.105
Up. N	0.716	–0.342	0.546	–0.018	–0.100	0.873	0.345	0.022
Up. P	0.891	–0.072	0.428	0.074	0.313	0.915	–0.001	0.066
Up. K	0.819	0.518	0.024	0.026	0.576	0.802	0.115	0.054
Chl. A	0.406	0.634	0.467	–0.236	0.775	0.379	–0.140	–0.292
Chl. B	–0.014	0.974	0.178	–0.026	0.913	–0.043	0.270	0.028
TSS	0.033	0.042	0.772	–0.587	0.058	0.161	0.912	–0.316
Sucrose	0.068	0.117	0.918	0.212	0.053	0.268	0.792	0.532
Purity	0.021	0.081	0.081	0.988	–0.005	0.114	–0.114	0.966
Yield	0.808	0.413	0.126	–0.266	0.609	0.648	0.135	0.150
Dry weight	0.717	0.503	–0.098	0.176	0.368	0.643	0.316	0.306
Eigenvalue	6.99	2.53	1.78	1.44	7.88	2.05	1.59	1.14
Variance %	49.96	18.06	12.71	10.30	56.25	14.65	11.35	8.13
CV %	49.96	68.02	80.73	91.03	56.25	70.91	82.26	90.39

OM Organic matter, *Av.N* available nitrogen, *Av.P* available phosphorus, *Av.K* available potassium, *Up.N, P, K* Uptake nitrogen, phosphorus and potassium, *Chl. A, B* = Chlorophyll A, B, *TSS* Total soluble solids

there is a weak positive relationship between purity (0.966) and sucrose content (0.532).

Discussions

Applying sheep manure to soil is known to increase SOM content due to sheep manure is easily degradable and stabilized organic matter. Nevertheless, application of SP and RP alone or combined with sheep manure increased organic matter due to the input of OM and nutrients from the organic amendments (Awad et al. 2021, 2022). Similarly, Janati et al. (2022) found that an increase in a compost based on waste plant, sheep manure, and rock phosphate application rate from 10 to 25 t ha^{-1} and from 25 to 40 t ha^{-1} increased SOM content by 13% and 69%, respectively.

Our results showed a decrease pH in all treatments. The hydrolysis of SM may also result in the release of organic acids, which could lower the soil pH. A slight change in soil pH has a considerable impact on the available phosphorus in the soil. Moreover, phosphorous is released in the system by the chemical reaction as a result of lowering pH by partial acidulation in the soil so it can be taken by plants or tends to alteration (Saied et al. 2022). The reduction in soil reaction (pH) may be more obvious with time due to soil microbial activity. This result is in convention with that observed by El-Tayeh et al. (2019) and Ali et al. (2021). Application of RP and/or SP increased soil salinity, which may be attributed to the high content of salts and alkaline substances. This effect was more pronounced when combined both RP and SP. This result agreed with that obtained by El-Tayeh et al. (2019) whom found that EC values regularly increased by adding organic materials (filter mud cake) at 10, 30, and 50% rates where the EC values of the tested soil were 0.55, 1.64, and 2.73 dS/m, respectively. Also, Khan et al. (2019), Youssef and Eissa (2017) and Ali et al. (2021) stated that adding manure caused a significant increase in salt and organic matter in soil especially sheep manure.

Adding various P sources with sheep manure fertilization increased available N, P, and K. The increase in the content of available NPK under combined application of sheep manure and sources of P fertilizers could be ascribed to the direct addition of RP, SP of SM added to the soil, and its decomposition as well as the raise the nutrient availability specially N caused by the decomposition of microorganisms to the soil native nutrients as indirect effect. This observation may indicate that using organic fertilizers have the ability to supply the growing plants by dissolved nutrients as a result of the acids they secrete which reduce the soil reaction increase macronutrient uptake process in plant tissues. After mineralization, SM supplies the soil with organic acids that dissolve soil nutrients and make them available for the plants (Bertand and Cleyetmarel 2008; Mondal et al. 2015; Awad et al. 2022).

Application of organic manure combined with sources of phosphorous fertilizers increased the content of available phosphorus. The application of rock phosphate and super-

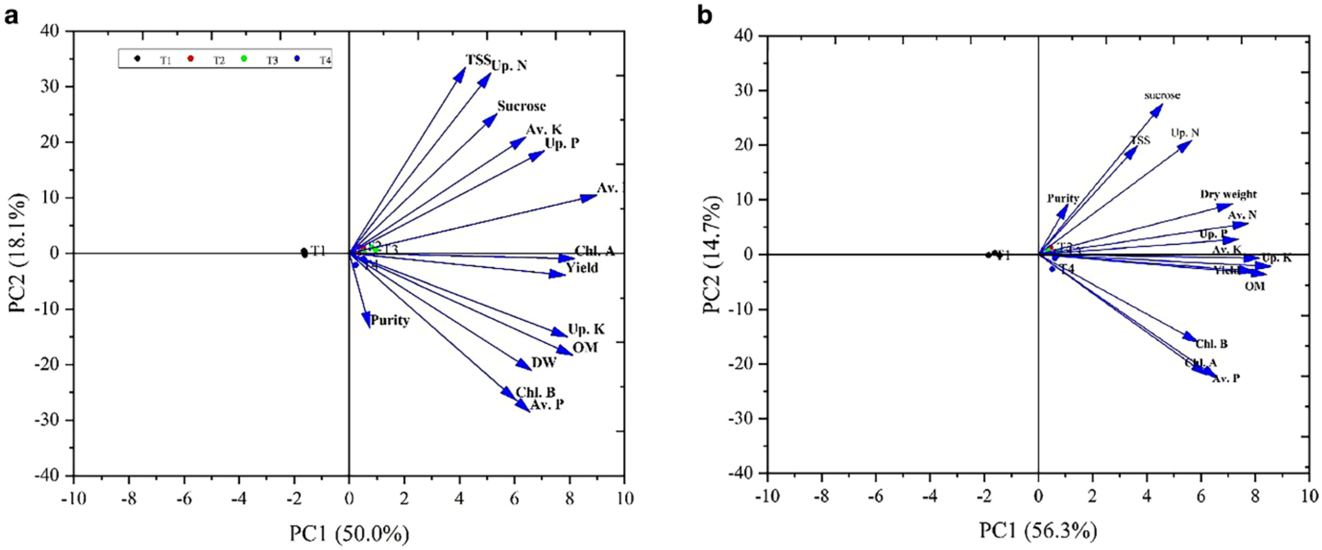

Fig. 4 PCA of investigating soil and sugar beet parameters: projection of active variables on a PCA factor plane for two seasons: **a** first and **b** second

phosphate together increased the availability of soil Olsen P by 59.67% compared to the sole application of rock phosphate, and by 30.10% compared to the sole application of superphosphate.

The sole application of rock phosphate or superphosphate to the soil was less effective than the combined application of the two amendments in increasing the availability and the uptake of nutrients by the sugar beet plants; this may be due to the great increase in the availability of P occurring in the soil when the two amendments were applied together (Eissa 2016). Plant-available K contents were higher in rock phosphate alone and a combination of super with rock phosphate in the first and second seasons respectively. This result is related to the ongoing release of available K from sheep manure during the two seasons.

In general, the combined application of P fertilizers enhanced sugar beet growth and development, and there was an increase in chlorophyll content as a result of increased soil P availability. Addition of P fertilizers combined with organic amendments is considered a successful management tool, improving the availability of soil macronutrients, especially under arid and semi-arid. However, application of organic amendments combined with P fertilizers also increased chlorophyll content (Karanatsidis and Berova 2014). Organic amendments can physiologically influence plant growth by releasing plant growth-regulating substances. This increase may be due to using P fertilizer or organic fertilizers that have the ability to supply the growing plants with dissolved nutrients as a result of the acids they secrete which reduce the soil reaction and ease the macronutrient uptake process in plant tissues (Li et al. 2021 and Eissa et al. 2013).

In the current study, an increase in chlorophyll a and b by 16.81 and 40.68% respectively at co-application rock phosphate with superphosphate. Chlorophyll a is responsible for the absorption of photons and plays a critical role in photosynthesis, whereas chlorophyll b also contributes to the transfer of light radioactive energy (Porcar-Castell et al. 2014; Siedliska et al. 2021).

All of this plays an important role in increasing vegetative growth and then photosynthesis pigments. This result was consistent with Abo Elazm (2008) and Youssef (2011) on marjoram plants. Bokhtiar and Sakurai (2005) reported that the chlorophyll content of leaf tissues was slightly increased by addition organic wastes (press mud, farmyard manure and sheep manure) and green manure.

Our study clearly indicated that the rock and superphosphate addition under the addition of sheep manure had a positive role in increasing the essential plant nutrients uptake. The increases in nutrient uptake, due to sheep manure addition, may be due to the improvement of soil quality. Organic matter addition may lead to an improvement in aeration and consequently an optimal root growth, thereby an increase in nutrient uptake and growth (Geng et al. 2019; Yang et al. 2021; Al-Sayed et al. 2023).

Co-application of organic fertilizers with RP and SP caused a visible enrichment in nutrient uptake by sugar beet plant, contributing to increase total yield. The uptake of phosphorus by beet roots was high compared to the control. Similar results were observed by (Zafar-ul-Hye et al. 2019) pointed that using manure alone or in combination with other biochar increases plant photosynthesis and nutrients uptake, which improves root/plant growth and increase the yield. The interaction of RP-blended SP mineral fertilizers, and SM also significantly increased the sugar beet yield by 25.72% over the control. This could be due to the root yield of sugar beet responded to combined RP and blended SP along with organic fertilizers as a result of increased soil organic matter, improved soil chemical properties, and increased nutrient availability, which helps to maintain soil nutrient status (Beura et al. 2019; Izhar Shafi et al. 2020; Shiberu et al. 2023). A combination of SP and RP was found to give higher sugar beet yields than fertilizer only, attributed to the increased agronomic efficiency due to the combined application. The result thus shows a significant increase in sugar beet yield due to either superphosphate or rock phosphate can be explained as a result of the reaction between water-soluble P with apatite P-produced materials act as slow-release P fertilizer for sustainable agriculture. Our results are in agreement with (Saied et al. 2022).

The level of root yield obtained was relatively high and significantly exceeded, which reflects the effect of treatments on the fertility of the study site (Górski et al. 2022). This assumption is consistent with the findings of Maharjan and Hergert (2019), who found that using organic fertilizer (FYM) increased sugar beet yield. This indicated that the synergetic roles of mineral and organic fertilizers enhanced the productivity of the crop as observed in this study.

However, sugar beet quality obtained was suitability significantly, which reflects the effect of treatments on the soil fertility of the study site. The increment in sucrose % may be due to the role of phosphorus in improving growth and dry matter accumulation by increasing the uptake and availability of most nutrients, consequently enhancement sucrose contentin roots, also such might be due effect of organic fertilization, which important role in improving soil nutrients release as a result of the acids they secrete which reduce the soil reaction increase macronutrient uptake process in plant tissues. These findings are in line with Mahmoud et al. (2012); Abdou et al. (2014); El-Mansoub et al. (2014); Ghaly et al. (2019).

Conclusion

Combined application of different natural materials even organic or raw rock as fertilizers recognized positive impacts on the growth, quality, and sugar beet yield and improves soil properties. Combined rock phosphate and superphosphate with sheep manure significantly boost vegetative growth, yield, and sugar beet plants quality. This improvement would highly help in development of organic farming techniques and considerably reduce production cost and environmental hazards. Although the application of sheep manure (SM) combined with superphosphate and rock phosphate with mixing ratio of 50:50 (T4) give the appropriate fresh weight of sugar beet roots, but the addition of SM with recommended dose of superphosphate (T3) give the highest sucrose percentage.

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References

Abdelgalil SA, Kaddah MM, Duab ME, Abo-Zaid GA (2022) A sustainable and effective bioprocessing approach for improvement of acid phosphatase production and rock phosphate solubilization by Bacillus haynesii strain ACP1. Sci Rep 12(1):8926. https://doi.org/10.1038/s41598-022-11448-6

Abdou MA, Awad NMM, Ibrahim MEM (2014) Influence of ploughing depth, phosphorus fertilizer level and thinning date on sugar beet productivity and quality. J Plant Prod 5(12):2037–2045. https://doi.org/10.21608/jpp.2014.64773

Abo Elazm M A I (2008) The effect of organic and bio-fertilization sources on the growth and active constituents of Majorana Hortensis L. plant (Doctoral dissertation, MSc Thesis, Fac. Agric., Al-Azhar Univ).

Al-Sayed HM, Hegab SA, Youssef MA, Khalafalla MY (2019) Integrated effect of inorganic and organic nitrogen sources on growth and yield of roselle (Hibiscus sabdariffa L.). Assiut J Agric Scie 50(3):164–183. https://doi.org/10.21608/ajas.2019.52773

Al-Sayed HM, Hegab SA, Youssef MA, Khalafalla MY, Eissa MA (2022) Compost and non-symbiotic nitrogen fixers to reduce inorganic-N rates for roselle (Hibiscus sabdariffa L.). Commun Soil Sci Plant Anal. https://doi.org/10.1080/00103624.2022.2118289

Al-Sayed HM, Khalafalla MY, Ali AM (2023) Effects of compost and biofertilizer on carbon dioxide emission, yield, and quality of roselle (Hibiscus sabdariffa L.) plants grown on clay loam. J Plant Nutr 46(11):1–17. https://doi.org/10.1080/01904167.2022.2160749

Ali AM, Awad MY, Hegab SA, El Abd Gawad AM, Eissa MA (2021) Effect of potassium solubilizing bacteria (Bacillus cereus) on growth and yield of potato. J Plant Nutr 44:411–420. https://doi.org/10.1080/01904167.2020.1822399

Ali AM, Hegab SA, El Gawad AAM, Awad MY (2022) Integrated effect of filter mud cake combined with chemical and biofertilizers to enhance potato growth and its yield. J Soil Sci Plant Nutr 22(1):455–464. https://doi.org/10.1007/s42729-021-00661-3

Ateia EM, Osman YAH, Meawad AEAH (2009) Effect of organic fertilization on yield and active constituents of Thymus vulgaris L. under North Sinai conditions. J Agric Biol Sci 5(4):555–565

Awad M, Liu Z, Skalicky M, Dessoky ES, Brestic M, Mbarki S, Rastogi A, El Sabagh A (2021) Fractionation of heavy metals in multi-contaminated soil treated with biochar using the sequential extraction procedure. Biomolecules 11(3):448. https://doi.org/10.3390/biom11030448

Awad M, Ali AM, Hegab SA, El Gawad AM (2022) Organic fertilization affects growth and yield of potato (Cara. cv) plants grown on sandy clay loam. Commun Soil Sci Plant Anal 53(6):688–698. https://doi.org/10.1080/00103624.2022.2028808

Bertand HC, Cleyetmarel JC (2008) Stimulation on the ionic transport system in tomato plants. Can J Microbiol 66:922–930

Beura K, Singh M, Pradhan AK, Rakshit R, Lal M (2019) Dissolution of dominant soil phosphorus fractions in phosphorus-responsive soils of Bihar, India: Effects of Mycorrhiza and fertilizer levels. Commun Soil Sci Plant Anal 50(3):287–294. https://doi.org/10.1080/00103624.2018.155

Bokhtiar SM, Sakurai K (2005) Integrated use of organic manure and chemical fertilizer on growth, yield, and quality of sugarcane in high Ganges river floodplain soils of Bangladesh. Commun Soil Sci Plant Anal 36(13–14):1823–1837. https://doi.org/10.1081/CSS-200062460

Burt R (2004) Soil Survey Laboratory methods manual. Soil Survey Investigations Report No. 42, Version 4.0.. Natural Resources Conservation Service, United States Department of Agriculture

Chew KW, Chia SR, Yen HW, Nomanbhay S, Ho YC, Show PL (2019) Transformation of biomass waste into sustainable organic fertilizers. Sustainability 11(8):2266. https://doi.org/10.3390/su11082266

Eissa MA (2016) Phosphate and organic amendments for safe production of okra from metal. J Soil Contam Agron 108(2):540–547. https://doi.org/10.2134/agronj2015.0460

Eissa MA, Nafady M, Ragheb H, Attia K (2013) Effect of soil moisture and forms of phosphorus fertilizers on corn production under sandy calcareous soil. World Appl Sci J 26(4):540–547

El-Kherbawy M, Abou-Zeid S, El-Aila H, Afify R, Zaghloul A (2014) Chemical characterization of phosphate rock applied in Arid region. Middle East J Agric Res 3:59–70

El-Mansoub MMA, Mohamed HY (2014) Effect of sowing dates and phosphorus fertilizer on root rot and quality of some sugar beet varieties. J Plant Prod 5(5):745–764. https://doi.org/10.21608/jpp.2014.53900

El-Sayed M A (2021). Studies on some soils of Wadi Tag El-Wabar, west of Sohag, Egypt, using remote sensing and geographic information systems techniques. Ph. D. Thesis, Fac Agric. Al-Azhar Univ Assiut, Egypt.

EL-Sharnoby HM (2021) Sugarbeet growth, yield components, quality and nitrogen use efficiency as influenced by sources and rates of nitrogen fertilizer. Alex Sci Exch J 42(2):273–285. https://doi.org/10.21608/ASEJAIQJSAE.2021.165933

El-Tayeh N, Salama F, Loutfy N, Abou Alhamd M (2019) Effect of sandy soil amendment with filter mud cake on growth and some ecophysiological parameters of Daucus carota and Beta vulgaris plants. Catrina Int J Environ Sci 18(1):97–103. https://doi.org/10.21608/cat.2019.28613

Elias E, Okoth PF, Smaling EMA (2019) Explaining bread wheat (Triticum aestivum) yield differences by soil properties and fertilizer rates in the highlands of Ethiopia. Geoderma 339:126–133. https://doi.org/10.1016/j.geoderma.2018.12.020

Geng Y, Cao G, Wang L, Wang S (2019) Effects of equal chemical fertilizer substitutions with organic manure on yield, dry matter, and nitrogen uptake of spring maize and soil nitrogen distribution. PLoS ONE 14(7):e219512. https://doi.org/10.1371/journal.pone.0219512

Ghaly F, Abd-Hady M, Abd-Elhamied A (2019) Effect of varieties, phosphorus and boron fertilization on sugar beet yield and its quality. J Soil Sci Agric Eng 10(2):115–122. https://doi.org/10.21608/JSSAE.2019.36679

Górski D, Gaj R, Ulatowska A, Miziniak W (2022) Effect of strip-till and variety on yield and quality of sugar beet against conventional tillage. Agriculture 12(2):166. https://doi.org/10.3390/agriculture12020166

Güneş A, Keçe YM, Beyzi E (2023) The effects of using organic and chemical fertilizers on yield and yield parameters in different pepper (capsicum annuum L.) varieties. Gesunde Pflanz. https://doi.org/10.1007/s10343-022-00811-2

Hafez M, Popov AI, Rashad M (2021) Integrated use of bio-organic fertilizers for enhancing soil fertility-plant nutrition, germination status and initial growth of corn (Zea mays L.). Environ Technol Innov 21:101329. https://doi.org/10.1016/j.eti.2020.101329

Hergert GW (2011) Sugar beet fertilization. Int J Sugar Crop Relat Ind 12:256–266. https://doi.org/10.1007/s12355-010-0037-1

Hlisnikovský L, Menšík L, Křížová K, Kunzová E (2021) The effect of farmyard manure and mineral fertilizers on sugar beet beetroot and top yield and soil chemical parameters. Agron 11(1):133. https://doi.org/10.3390/agronomy11010133

Izhar Shafi M, Adnan M, Fahad S, Wahid F, Khan A, Yue Z, Datta R (2020) Application of single superphosphate with humic acid improves the growth, yield and phosphorus uptake of wheat (Triticum aestivum L.) in calcareous soil. Agron 10(9):1224. https://doi.org/10.3390/agronomy10091224

Jackson ML (1973) Soil chemical analysis. Prentice-Hall, Englewood Cliffs, New Delhi

Janati ME, Akkal-Corfini N, Robin P, Oukarroum A, Sabri A, Thomas Z, Bouaziz A (2022) Compost from date palm residues increases soil nutrient availability and growth of silage corn (Zea mays L.) in an arid agroecosystem. J Soil Sci Plant Nutr 22(3):3727–3739. https://doi.org/10.1007/s42729-022-00922-9

Karanatsidis G, Berova M (2014) Effect of organic-N fertilizer on growth and some physiological parameters in pepper plants (Capsicum annum L.). Biotechnol Biotechnol Equip 23(sup1):254–257. https://doi.org/10.1080/13102818.2009.10818413

Khan M, Billah M, Ahmad S, Khan RU, Sarwar M (2019) Assessment of formulated phosphorus enriched compost on rice followed wheat crop yields. Pak J Agric Sci 32(4):6477–6655. https://doi.org/10.17582/journal.pjar/2019/32.4.647.655

Le Docte A (1927) Commercial determination of sugar in the beet root using the Sacks-Le Docte process. Int Sug J 29:488–492

Li J, Ali EF, Majrashi A, Eissa MA, Ibrahim OH (2021) Compost enhances forage yield and quality of river saltbush in arid conditions. Agriculture 11(7):595. https://doi.org/10.3390/agriculture11070595

Lichtenthaler HK (1987) Chlorophylls and careteniods pigments of photosynthetic biomembranes. Methods Enzymol 148:183–350

Maharana R, Basu A, Dhal NK, Adak T (2021) Biosolubilization of rock phosphate by Pleurotus ostreatus with brewery sludge and its effect on the growth of maize (Zea mays L.). J Plant Nutr 44(3):395–410. https://doi.org/10.1080/01904167.2020.1822397

Maharjan B, Hergert GW (2019) Composted cattle manure as a nitrogen source for sugar beet production. J Agron 111(2):917–923

Mahmoud EA, Hassanin MA, Emara EI (2012) Effect of organic and mineral nitrogenous fertilizers and plant density on yield and quality of sugar beet (Beta vulgaris L.). Egypt J Agron 34(1):89–103

Ministry of Agriculture and Land Reclamation (2019) Sugar crops and sugar production in Egypt and the world; MALR annual report. Council of Sugar Crops, Giza

Mondal NK, Datta JK, Arnab B (2015) Integrated effects of reduction dose of nitrogen fertilizer and mode of bio-fertilizer application on soil health under mung bean cropping system. Commun Plan Sci 5(1/2):15–22

Moussa SB, Bachoua H, Badraoui B, Fatteh N (2016) Physico-chemical investigations of hydroxyapatite converted from phosphate rocks of M'dhilla deposit. J Mater Environ Sci 7(5):1810–1818

Oladosu Y, Rafii MY, Arolu F, Chukwu SC, Salisu MA, Fagbohun IK, Muftaudeen TK, Swaray S, Haliru BS (2022) Superabsorbent polymer hydrogels for sustainable agriculture: a review. Horticulturae 8(7):605

Olsen SR, Cole CV, Watanabe FS, Dean LA (1954) Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department of Agriculture Circular, Washington, DC, p 19

Page AL, Miller RH, Keeney DR (1982) Methods of soil analysis. Part 2. Chemical and microbiological properties, 2nd edn. Am. Soc. Agron Inc Soil Sci Soc. Am, Madison

Paramesh V, Ravisankar N, Behera U, Arunachalam V, Kumar P, Rajkumar SR, Dhar Misra S, Kumar MR, Prusty AK, Jacob D, Panwar AS (2022) Integrated farming system approaches to achieve food and nutritional security for enhancing profitability, employment, and climate resilience in India. Food Energy Secur 11(2):321. https://doi.org/10.1002/fes3.321

Parewa HP, Rakshit A, Rao AM, Sarkar NC, Raha P (2010) Evaluation of maize cultivars for phosphorus use efficiency in an Incept sol. Int J Agric Environ Biotechnol 3(2):195–198

Porcar-Castell A, Tyystjärvi E, Atherton J, Van der Tol C, Flexas J, Pfündel EE, Berry JA (2014) Linking chlorophyll a fluorescence to photosynthesis for remote sensing applications: mechanisms and challenges. J Exp Bot 65(15):4065–4095. https://doi.org/10.1093/jxb/eru191

Rehab I, El Maghraby SS, Kandil EE, Ibrahim NY (2019) Productivity and quality of sugar beet in relation to humic acid and boron fertilization under nubaria conditions. Alex Sci Exch J 40:115–126. https://doi.org/10.21608/asejaiqjsae.2019.29029

Saied HS, Aboelenin SM, Kesba H, El-Sherbieny AE, Helmy AM, Dahdouh SM, Soliman MM (2022) Chemical evaluation of partially acidulated phosphate rocks and their impact on dry matter yield and phosphorus uptake of maize. Saudi J Biol Sci 29(5):3511–3518. https://doi.org/10.1016/j.sjbs.2022.02.022

Shiberu ED, Dachassa N, Desalegn T, Balami T (2023) Effect of applying integrated mineral and organic fertilizers on seed yield, yield components and seed oil content of black cumin in central highlands of Ethiopia. Int J Hortic Sci 10(1):97–114

Siedliska A, Baranowski P, Pastuszka-Woźniak J, Zubik M, Krzyszczak J (2021) Identification of plant leaf phosphorus content at different growth stages based on hyperspectral reflectance. BMC Plant Biol 21:1–17. https://doi.org/10.1186/s12870-020-02807-4

Steel RGD, Torrie JH (1986) Principle and procedure of statistics. A Biometrical approach, 2nd edn. McGraw-Hill, New York

Sugar Crops Council (2020) Annual report "Sugar crops and sugar production in Egypt in 2018/2019 growing and Juice 2020 season"

Teng Z, Zhu J, Shao W, Zhang K, Li M, Whelan MJ (2020) Increasing plant availability of legacy phosphorus in calcareous soils using some phosphorus activators. J Environ Manage 256:109952. https://doi.org/10.1016/j.jenvman.2019.109952

Torri SI, Correa RS, Renella G (2017) Biosolid application to agricultural land—a contribution to global phosphorus recycle: a review. Pedosphere 27(1):1–16. https://doi.org/10.1016/S1002-0160(15)60106-0

Van Eerd LL, Congreves KA, Zandstra JW (2012) Sugar beet (Beta vulgaris L.) storage quality in large outdoor piles is impacted by pile management but not nitrogen fertilizer or cultivar. Can J Plant Sci 92(1):129–139. https://doi.org/10.4141/cjps2011-054

Victor Roch G, Maharajan T, Ceasar SA, Ignacimuthu S (2019) The role of PHT1 family transporters in the acquisition and redistribution of phosphorus in plants. CRC Crit Rev Plant Sci 38(3):171–198. https://doi.org/10.1080/07352689.2019.1645402

Yadav C, Pandey S (2018) Isolation and characterization of phosphate solubilizing bacteria from agriculture soil of Jaipur, Rajasthan. Int J Recent Trends Sci Technol 8(20):180–191

Yang C, Du W, Zhang L, Dong Z (2021) Effects of sheep manure combined with chemical fertilizers on maize yield and quality and spatial and temporal distribution of soil inorganic nitrogen. Complexity. https://doi.org/10.1155/2021/4330666

Youssef MA (2011) Synergistic impact of effective microorganisms and organic manures on growth and yield of wheat and marjoram plants. Ph. D. Thesis, Fac. Agric., Assiut Univ., Assiut, Egypt.

Youssef MA, Eissa MA (2017) Comparison between organic and inorganic nutrition for tomato. J Plant Nutr 40(13):1900–1907. https://doi.org/10.1080/01904167.2016.1270309

Zafar-ul-Hye M, Danish S, Abbas M, Ahmad M, Munir TM (2019) ACC deaminase producing PGPR Bacillus amyloliquefaciens and Agrobacterium fabrum along with biochar improve wheat productivity under drought stress. Agronomy 9(7):343. https://doi.org/10.3390/agronomy9070343

Zhu J, Li M, Whelan M (2018) Phosphorus activators contribute to legacy phosphorus availability in agricultural soils: a review. Sci Total Environ 612:522–537. https://doi.org/10.1016/j.scitotenv.2017.08.095

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