



Article

The Fusion Impact of Compost, Biochar, and Polymer on Sandy Soil Properties and Bean Productivity

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Abstract: Two of the most significant issues confronting arid and semi-arid countries are soil degradation and the need to reclaim sandy soils and improve their properties to enhance the agricultural area and ensure food security. Many attempts to improve sandy soil properties have been attempted using soil amendments, but further research is needed to explore the combined impact of cost-effective amendments. To that purpose, we investigated the impact of various soil amendments, including single and combination applications of synthetic Super Absorbent Polymer (SAP), compost, and biochar, on sandy soil physiochemical characteristics and bean (*Vicia faba* L.) production and quality throughout three growing seasons. In a randomized complete block design with three replicates per treatment, different treatments such as control (without application), lower dose of SAP (SAP1), higher dose of SAP (SAP2), biochar, compost, SAP1 plus biochar, SAP1 plus compost, SAP2 plus biochar, SAP2 plus compost, and biochar plus compost were used. The combined treatments, such as SAP2 plus biochar (T8), SAP2 plus compost (T9), and biochar plus compost (T10), improved soil physiochemical characteristics and crop production significantly. Application of T10 decreased soil bulk density by 15%, 17%, and 13% while increasing soil available water by 10%, 6%, and 3% over the first, second, and third growing seasons, respectively, compared to untreated soil (T1). The application of treatment (T9) surpassed other treatments in terms of yield, quality, and economic return, significantly increasing the seed yield by 24%, 26%, and 27% for the first, second, and third season compared with untreated soil. The higher rate of polymer combined with compost could be considered a cost-effective soil amendment to improve sandy soil productivity in arid and semi-arid regions.

Keywords: sandy soils; physical properties; chemical properties; yield quality; SAP polymer; economic return



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1. Introduction

According to estimates, 70% more food will be needed due to the world's rapid population growth in order to support the expected population of 9.6 billion people by 2050, with the majority of this need coming from developing nations and Africa [1,2]. In order to overcome this obstacle, it is necessary to boost crop production across the board, particularly in developing countries. Legumes are a key component of agricultural production systems and a major source of proteins and minerals, contributing mainly to human diets and farming systems [3,4]. Domestic *Vicia faba* production in Egypt fell three decades ago. Egypt's self-sufficiency in the crop was destroyed by a combination of political actions and environmental changes, resulting in the country's severe dependency on imports today. However, domestic bean (*Vicia faba* L. c.v. Nubaria 2) production is growing more slowly than needed to meet domestic consumption demands. Because of this, the faba bean food gap continues to grow [5]. In fact, the difference widened significantly,

growing by roughly 891% from 73 thousand tonnes in 2000 to about 650 thousand tonnes in 2016 [6]. To close the gap, bean production must be increased both horizontally and vertically, which requires high quality soils.

Soil quality can be described as the techniques used to improve the physical, chemical, and biological properties of soil [7]. Sandy soil is one of the most difficult challenges facing agricultural production, due to its characteristics of low fertility, low water holding capacity, extensive erosion, and high evaporation, requiring much attention to improve soil quality [8]. There have been numerous efforts made to enhance the characteristics of sandy soil, including applications of both organic [9,10] and inorganic amendments [11]. Among such amendments are biochar [12], vermicompost [13], recycled agricultural wastes [14], and synthetic Super Absorbent Polymer (SAP) [15]. Compost has long been used as an organic soil amendment to improve physiochemical and biological characteristics [16,17]. It can also improve soil fertility, structure, increase soil water holding capacity, and decrease erosion and runoff in sandy soils [8]. Biochar, which is made from pyrolyzed wastes that have a longer residence period than unpyrolyzed wastes, increases soil fertility by affecting the physiochemical and biological characteristics of the soil [18,19]. Many studies have shown that biochar has a good impact on soil characteristics and crop output [20–22]. Depending on the kind, dosage, and soil type, biochar features such as pH, increased surface area, cation exchange capacity, and nutrient content positively influence soil parameters and ultimately improve soil fertility [23]. The feedstock from which biochar is created, as well as its makeup and the type of soil to which it will be applied, all have a significant impact on the biochar application rate [22]. The combined effect of composts, biochar, and polymers on the physical and chemical characteristics of soil has not yet been studied in detail, confirming the importance of the current study. Understanding how changed composts alter soil structure and, subsequently, soil physical quality through soil micromorphological studies may be helpful.

Polymers are huge molecules made up of monomers, which are repeating units. Typically, polymerization of monomers results in the formation of polymers, which differ from monomers in both their physical and chemical characteristics. There have been reports of using both natural and synthetic polymers to stabilize soils [24]. Recently, there has been a focus on the use of synthetic polymers (SA) to stabilize soil properties and reduce deterioration in arid and semi-arid soils [25,26], but further research is needed to encompass a wider range of soils and settings. Therefore, the main objectives of this work are to (I) investigate the individual and combined effects of compost, biochar, and polymer in low and high rates on the physiochemical characteristics of sandy soil, and (II) study the response of bean yield and yield components to the application of these amendments in sandy soil conditions.

2. Materials and Methods

2.1. Study Location, Soil, and Weather Characteristics

The experiment was carried out in the Baltim area of Kafrelsheikh province in Egypt's north (Figure 1). The soil texture is sandy loam, with low fertility and water retention (Table 1). The region is located at the north of Egypt with low temperature and moderate precipitation (Figure 2), proving that soil properties are the main limiting factor in crop production. The study site represents the first agroclimatic zone in Egypt, which characterizes the moderate climate.

Table 1. The physiochemical properties of the study area before cultivation.

Chemical Characteristics	Value	Physical Characteristics	Value	Soil Moisture Content	Value
EC (paste extract) dS m ⁻¹	2.83	Particle size distribution (%)		FC%	5.70

Table 1. Cont.

Chemical Characteristics	Value	Physical Characteristics	Value	Soil Moisture Content	Value
pH (suspension 1:2.5 w:v)	7.79	Sand	68.96	WP%	15.00
SOC (g kg ⁻¹)	0.60	Silt	15.34	AW%	9.30
Available NPK (mg kg ⁻¹)		Clay	15.70		
N	15.36	Texture	Sandy loam		
P	4.81	CEC (cmolc kg ⁻¹)	0.90		
K	51.93	Bulk density (Mg m ⁻³)	1.58		

EC: electrical conductivity; SOC: soil organic carbon; CEC: cation exchange capacity; FC: field capacity; WP: permanent wilting point; AW: available water.

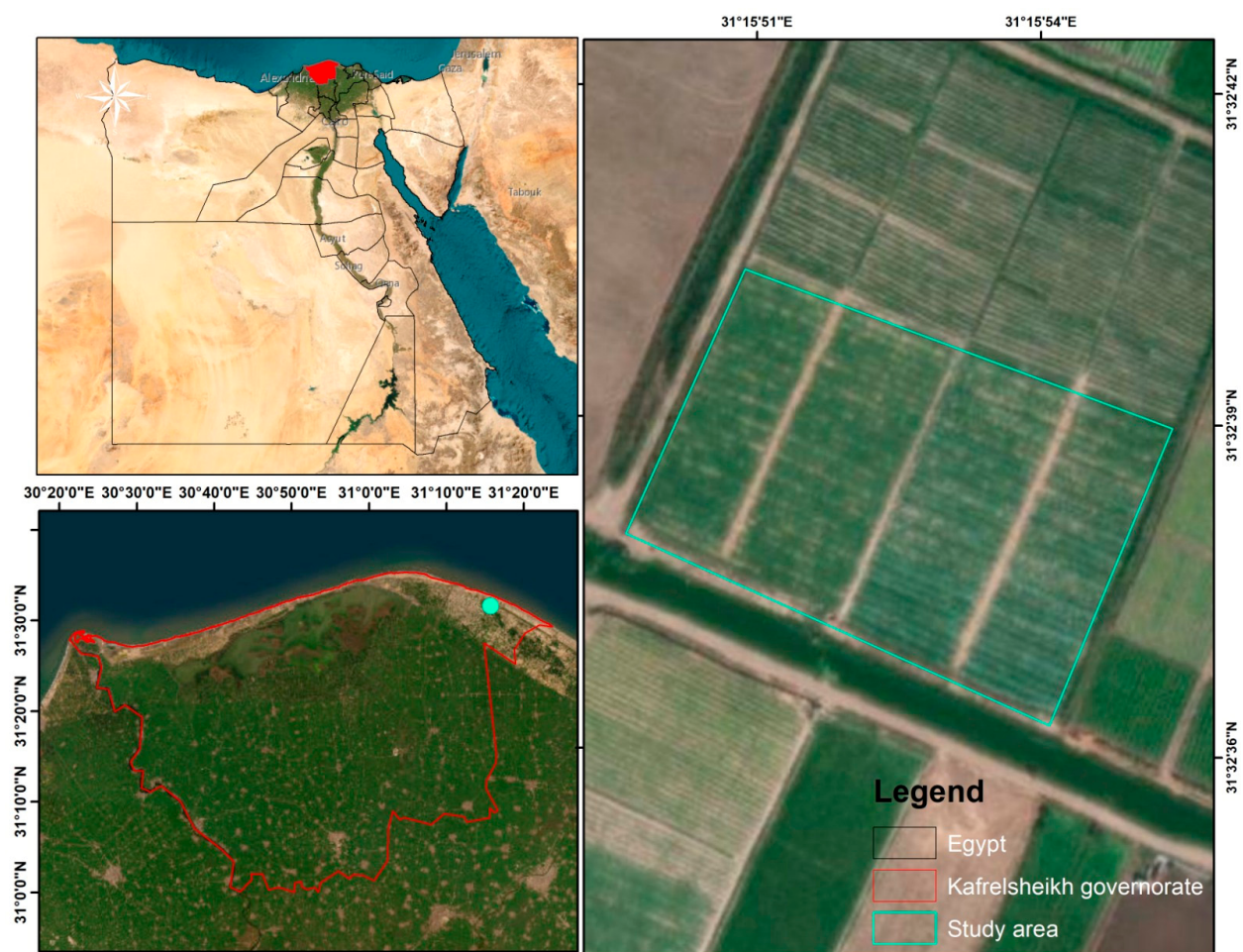


Figure 1. The study location of the field experiment at Baltim city, Kafr El-Sheikh governorate, Egypt.

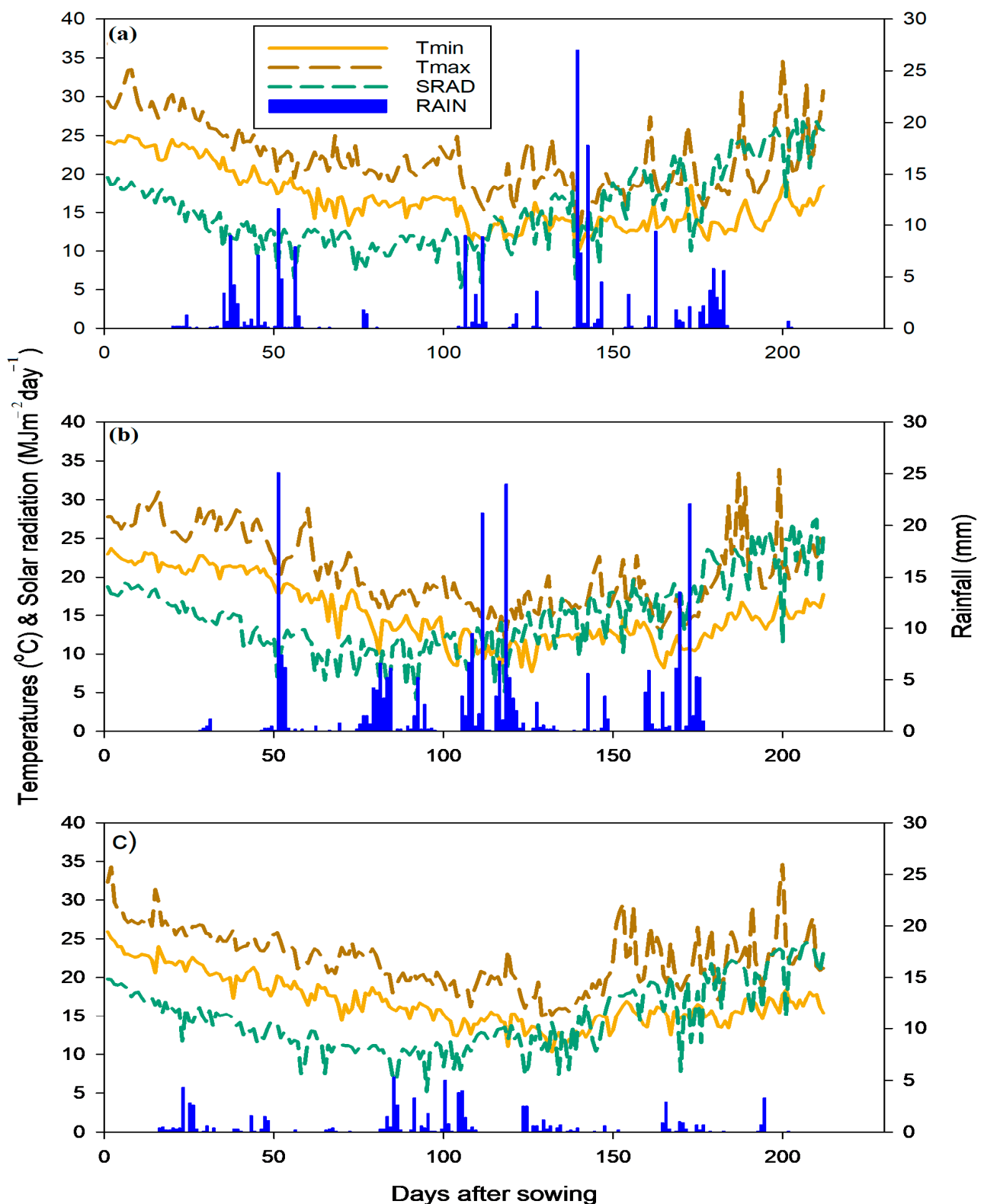


Figure 2. Daily weather data of minimum temperature (Tmin), maximum temperature (Tmax), solar radiation (SRAD), and rainfall for beans during three growing seasons, 2020/2021 (a), 2021/2022 (b), and 2022/2023 (c).

2.2. Experimental Design and Treatments

The field experiment, which included ten treatments, was set up in a randomized complete block design with three replicates per treatment. Individual plots included

compost, biochar, SAP polymer, and their mixtures as: T1: control (without addition); T2: SAP1 polymer at 5 g per hull (SAP1); T3: SAP2 polymer at 10 g per hull (SAP2); T4: biochar 5.88 tonnes per acre (B); T5: compost 11.75 tonnes per acre (C); T6: SAP1 + B; T7: SAP1 + C; T8: SAP2 + B; T9: SAP2 + C; and T10: B + C. The local cultivar Nubaria 2 was sown on 9 November in three successive growing seasons (2020/2021, 2021/2022, and 2022/2023). The area of the field experiment was 450 m² (36 lines + 9 lines free between all treatments); the distance between each line of 30 cm, with one seed placed per hull, and the distance between the holes along the line was 25 cm. Amendments of biochar and compost, as well as phosphorus, were given during seedbed preparation. Phosphorus fertilizer was applied at 60 kg P ha⁻¹ as ordinary Ca- superphosphate, and K was applied at 120 kg K ha⁻¹ as potassium sulphate. Nitrogen (N) was applied at 72 kg N ha⁻¹ as ammonium sulphate in three equal splits: 30, 45, and 60 days after sowing. SAP polymer was added after the line was prepared. faba beans were sown on 9 November in three seasons at 168 kg ha⁻¹ using a dry planting by hand method. At the harvest stage, after 142 days, soil and plant samples were collected for analysis.

2.3. Management Practices

Compost was prepared by the procedures described in [8], with the main properties of pH = 7.84, EC (saturation extract) 4.13 dS m⁻¹, organic matter content = 267.6 (g kg⁻¹), N = 17.6 (g kg⁻¹), P = 8.8 (g kg⁻¹), K = 12.2 (g kg⁻¹), and WHC = 126%. Corn waste was slowly pyrolyzed at 350 °C for 2.5 h to produce biochar. Super absorbent polymer (SAP; Polyacrylic acid) was provided by the Central Lab. of the Agric. Climate, Agric. Res. Centre, Giza, Egypt, with the main properties of pH = 7.12; BD = 0.67 Mg m⁻³; WHC = 600%; and composites (Bentonite + SAP – 20% and Kaolinite + SAP – 20%).

2.4. Soil and Plant Measurements

Before and after harvesting, soil samples were taken and subjected to normal procedures for chemical and physical analysis [27,28]. The pressure membrane method was used to test the soil moisture field capacity (FC) and permanent wilting point (PWP) at 0.1 and 15 bars, respectively. Using the pipette method, the particle size distribution of soil samples was measured. Using a cylindrical, sharp-edged core sampler, the bulk density of the soil was calculated [29]. The modified wet combustion method was used to measure the amount of soil organic carbon [30]. Conventional techniques were used to extract and determine the amount of N, P, and K in the soil [31]. During the three growing seasons, the contents of NPK in faba bean seeds were determined, along with the plant height (cm), weight of 100 seeds (g), HI (%), seed, straw, and biological yields (kg ha⁻¹).

2.5. Economic Return

Total cost, total return, and net return were computed based on the change in the exchange rate between the Egyptian pound and the US dollar between 9 November (planting date) and 30 March (harvest date) during three growing seasons.

2.6. Statistical Analysis

Regression analysis of soil physiochemical properties under different treatments and over different growing seasons, as well as pair plot visualization of all crop features under all treatments, were performed in Python using the seaborn and matplotlib packages [32]. Principle Component Analysis (PCA) for all crop features and treatments was conducted using the Factoextra in R language. Analysis of variance and least significant differences (LSD) ($p \leq 0.01$) were performed according to [33] using the agricolae package in R studio.

3. Results

3.1. Soil Physiochemical Properties Subjected to Amendment Application

Figure 3 indicates that amendments had a favourable influence on most soil characteristics, revealing that the addition of compost enhanced CEC, soil organic carbon, and

soil nitrogen content significantly throughout the first and second seasons, while the soil phosphorus and potassium concentration were excessive only in the first season. Biochar, on the other hand, increased soil phosphorus and potassium content during the last two seasons (2nd and 3rd), as well as CEC values and soil nitrogen content during the third season. Furthermore, both SAP dosages (SAP1 and SAP2) exhibited a negligible to minor effect on soil chemical characteristics. The lowest increase in values was recorded when no amendments were received. The maximum CEC and SOC values were obtained by combining biochar and compost application (T10). All the combinations, particularly those with biochar, boosted the NPK content of the soil.

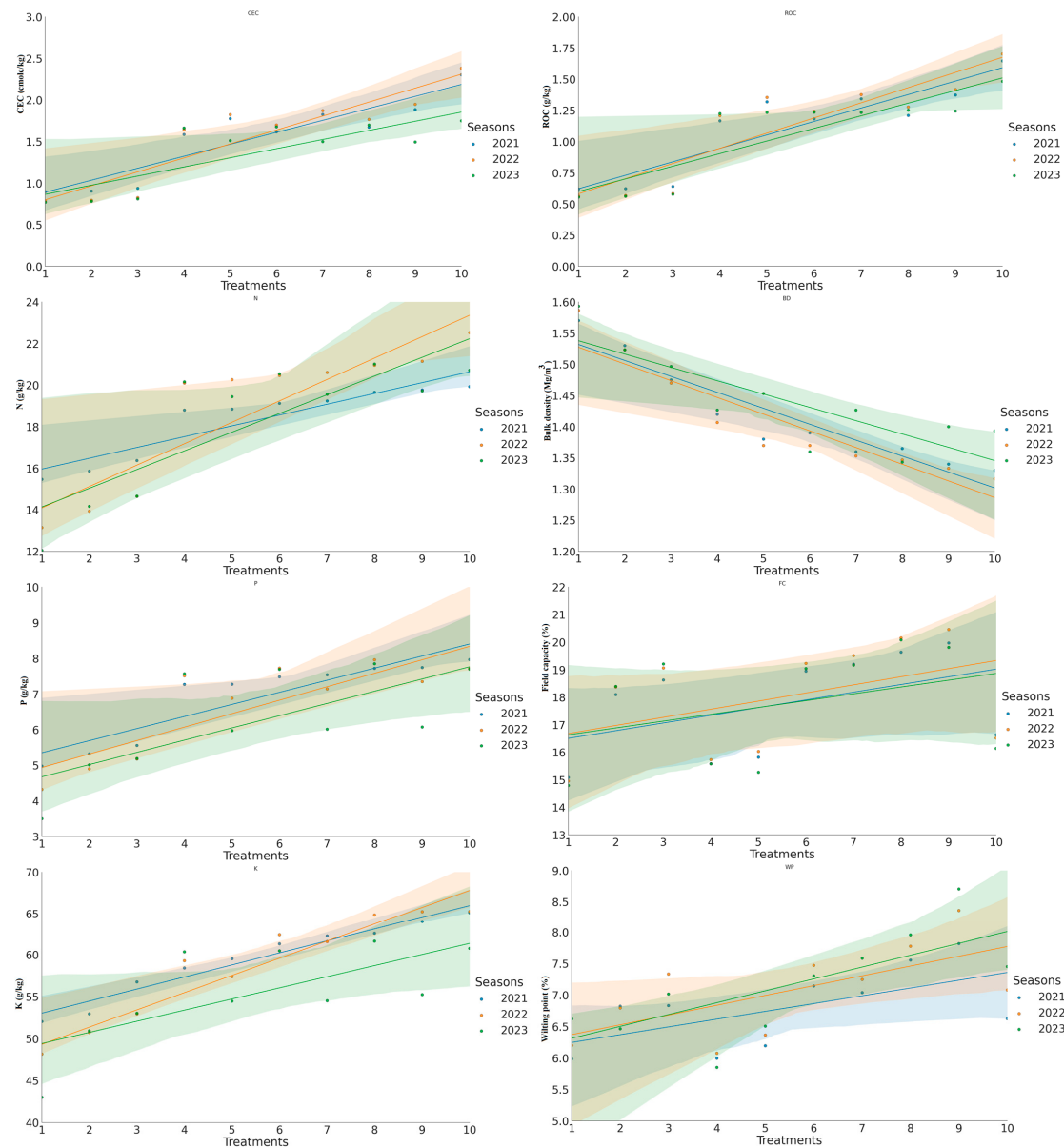


Figure 3. Regression between soil treatments and physiochemical properties over three growing seasons. The treatments are T1 to T9 as control, polymer5, polymer10, biochar2.5, compost5, polymer5 + biochar2.5, polymer10 + biochar2.5, polymer10 + compost5, and biochar2.5 + compost5, respectively. The neighbour numbers represent the amendment dose as (t/ha). The target soil properties are cation exchange capacity (CEC), nitrogen (N), phosphorus (P), potassium (K), organic carbon (ROC), bulk density, field capacity (FC), and permanent wilting point (WP).

Compost application reduced soil BD by an average of 13.77% and 15.82% in seasons 1 and 2, respectively, while biochar application reduced it by 11.68% in the third season. It was reduced by an average of 18.05%, 20.51%, and 18.61% in each season using biochar +compost (T10) or SAP2 + biochar (T8). The application of SAP polymer had a significant impact on increased soil moisture content, such as WP, FC, and AW, with the application of SAP2 in respective seasons increasing WP, FC, and AW by 14.19%, 23.43%, and 29.50% in the first season, 20.73%, 27.44%, and 32.03% in the second season, and 19.95%, 29.80%, and 36.23% in the third season. SAP1 caused increases of 14.03%, 19.95%, and 23.84%; 11.83%, 22.83%, and 30.35%; and 18.87, 24.29, and 27.84 in the first, second, and third seasons, respectively. A combination of treatments resulted in an increase in soil moisture content, outperforming other treatments. Application of SAP polymers used with both organic additions (biochar and compost) enhanced soil moisture content. On the other hand, for WP, FC, and AW, there were no significant changes between all the investigated combinations (Figure 3). According to the findings, the residual effect of compost diminished in the third season. The effect of biochar, on the other hand, showed an increasing curve during the second season, particularly in the soil content of elements, due to increased CEC values, while the effect of adding both polymer dosages on soil moisture content was obvious.

3.2. Faba Bean Yield and Traits Subjected to Amendment Application

The soil amendments had a significant effect on bean seed yield and yield components ($p < 0.001$), and this effect differed significantly across all treatments (Table 2 and Supplementary Figures S1–S8). The treatment of SAP2 plus biochar outperformed other treatments, with highly significant differences in seed yield, straw yield, plant height, and seed weight when averaged over three growing seasons. There are no significant differences between SAP2 + Biochar (T8), SAP2 + Compost (T9), and Biochar + Compost (T10), confirming that any treatment from them could be adopted as long as the biggest economic profit is achieved. The treatment (T10), on the other hand, revealed the best nutritional status in bean seeds (N, P, and K) with highly significant differences from the other treatments. faba bean yield and yield attributes responded positively to the fusion application of biochar, compost, and SAP polymer. The pair plot showed positive correlation between all traits except HI, which showed negative correlation with all traits (Figure 4). To properly grasp the correlations between soil amendment treatments, yield, and their qualities, the PCA analysis (loadings and scores) was applied (Figure 5). Yield, yield attributes, and qualities correlated positively with the treatments SAP2 + Biochar (T8), SAP2 + Compost (T9), and Biochar + Compost (T10), and negatively with the trait HI. This confirms the importance of applying SAP2 + Biochar (T8), SAP2 + Compost (T9), and Biochar + Compost (T10) in improving sandy soil properties and maximizing yield and quality in these conditions. However, as there are no significant differences between these treatments (SAP2 + Biochar (T8), SAP2 + Compost (T9), and Biochar + Compost (T10)), further economic analysis is required to select the optimum treatment that achieves the highest return for farmers.

Table 2. Statistical analysis of bean yield and traits after being subjected to different treatments of soil amendments averaged over three growing seasons.

Treatments	Seed Yield (kg ha ⁻¹)	Straw Yield (kg ha ⁻¹)	Plant Height (cm)	Seed Weight (g)	N in Seeds (%)	P in Seeds (%)	K in Seeds (%)
Control	1111.667 e	1290.683 d	141.0000 e	52.35657 d	2.100000 h	0.150 e	1.200 e
SAP1	1118.333 e	1288.967 d	144.3333 cd	59.25136 c	2.266667 g	0.156 e	1.206 e
SAP2	1267.333 c	1440.743 bc	147.3333 bc	62.08754 a	2.353333 f	0.170 e	1.240 e
Biochar	1160.000 de	1322.716 cd	142.6667 de	59.79686 c	2.406667 ef	0.200 d	2.063 b
Compost	1173.333 d	1342.977 bcd	143.6667 de	61.04588 b	2.576667 c	0.220 cd	1.740 d
SAP1 + Biochar	1225.000 c	1405.065 bcd	147.3333 bc	60.80972 b	2.466667 de	0.220 cd	2.093 b

Table 2. Cont.

Treatments	Seed Yield (kg ha ⁻¹)	Straw Yield (kg ha ⁻¹)	Plant Height (cm)	Seed Weight (g)	N in Seeds (%)	P in Seeds (%)	K in Seeds (%)
SAP1 + Compost	1265.000 c	1454.032 b	150.0000 b	62.08800 a	2.666667 b	0.243 bc	1.780 d
SAP2 + Biochar	1356.000 ab	1670.421 a	154.0000 a	62.16394 a	2.513333 cd	0.250 b	2.173 a
SAP2 + Compost	1386.333 a	1725.045 a	154.6667 a	62.88508 a	2.766667 a	0.263 ab	1.873 c
Biochar + Compost	1318.333 b	1716.747 a	154.3333 a	62.88155 a	2.826667 a	0.280 a	2.200 a
LSD	50.696	125.783	3.155	0.827	0.070	0.025	0.051
p value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
CV	2.404	5.038	1.252	0.802	1.667	6.888	1.713

Different letters to show statistical significance. For all variables with the same letter, the difference between the means is not statistically significant. If two variables have different letters, they are significantly different.

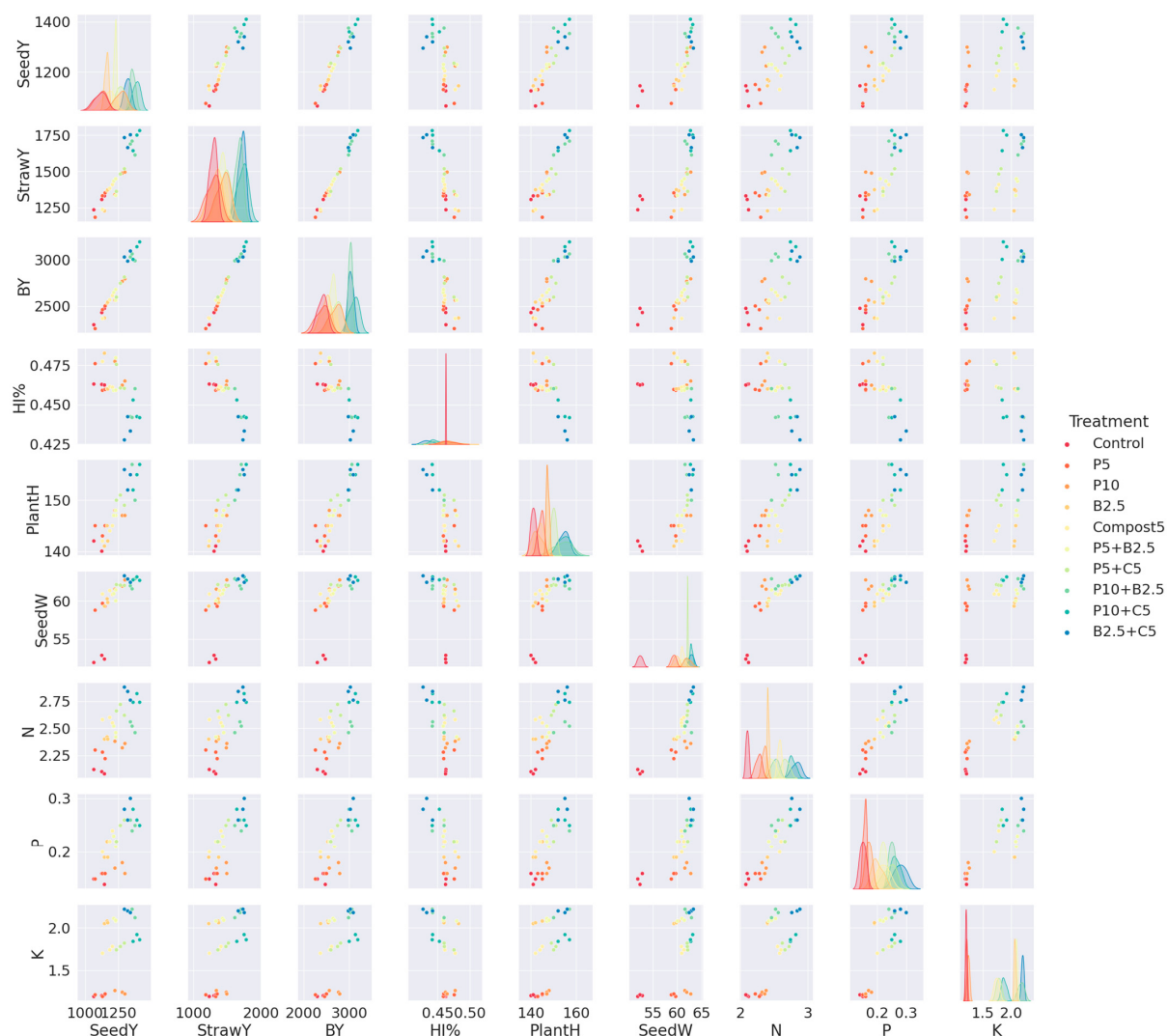


Figure 4. The pair plot represents the correlation between yield, yield attributes, and nutritional status of seeds under the corresponding treatments. The correlation performed was averaged over three growing seasons. The traits include seed yield (SeedY), straw yield (StrawY), biomass yield (BY), harvest index (HI), plant height (PlantH), seed weight (SeedW), nitrogen in seeds (N), phosphorus in seeds (P), and potassium in seeds (K). The treatments T1 to T10 are control, SAP1, SAP2, biochar, compost, SAP1 + biochar, SAP1 + compost, SAP2 + biochar, SAP2 + compost, and biochar + compost, respectively.

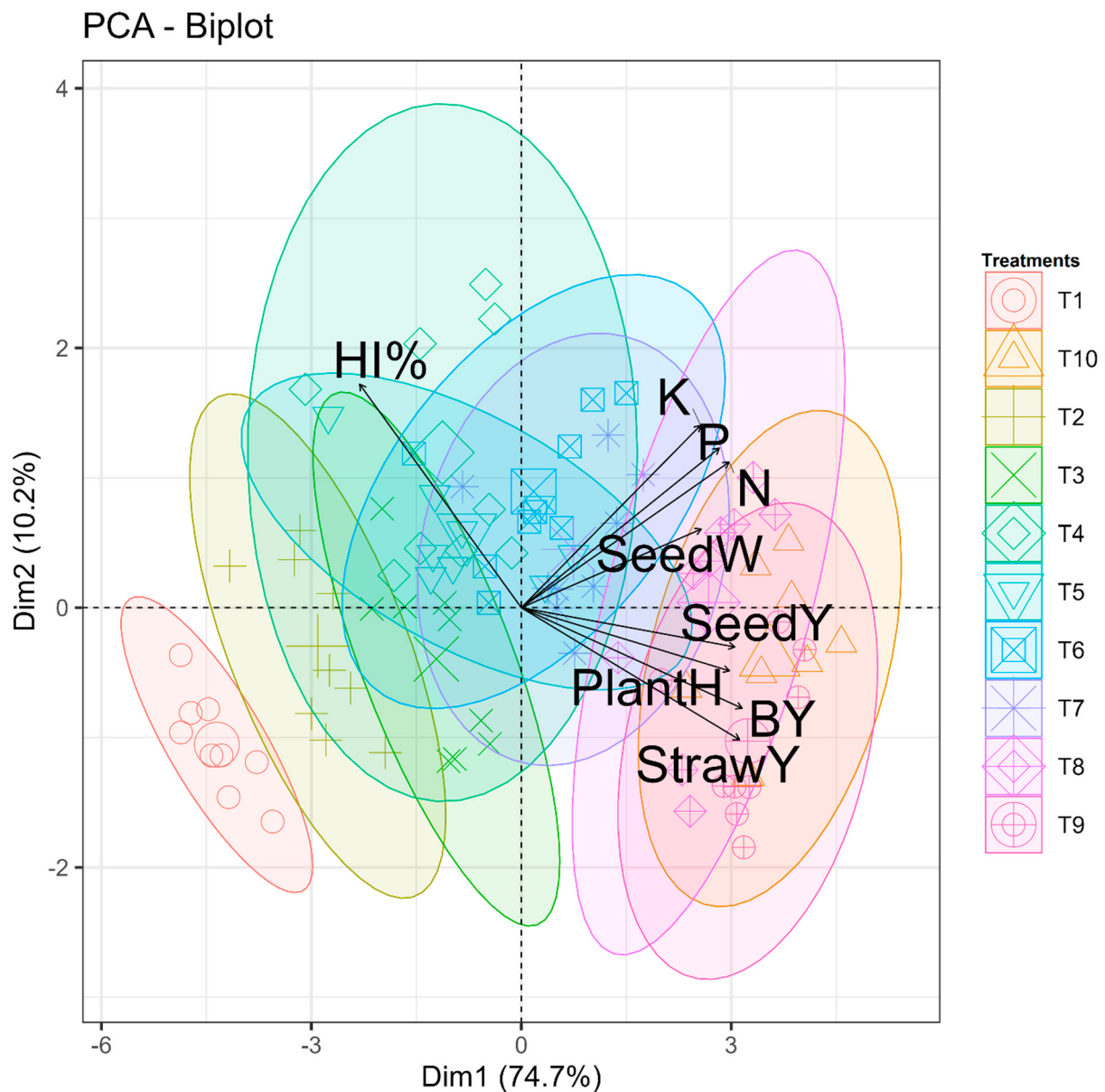


Figure 5. Principal component analysis (PCA) to better understand the variability of yield, yield attributes (loadings), and treatments (scores). The loadings include seed yield (SeedY), straw yield (StrawY), biomass yield (BY), plant height (PlantH), harvest index (HI), seed weight (SeedW), seed content of nitrogen (N), seed content of phosphorus (P), and seed content of potassium (K). The soil treatments (scores) included control, polymer5, polymer10, biochar2.5, compost5, polymer5 + biochar2.5, polymer5 + compost5, polymer10 + biochar2.5, polymer10 + compost5, and biochar2.5 + compost5 for T1, T2, T3, T4, T5, T6, T7, T8, T9, and T10, respectively.

3.3. Economic Returns

According to the results in Table 3, the expenses of adding amendments were high in the first season 2020/2021 compared to the control; therefore, the net return favoured the control over the new treatments. The difference was clear for all treatments compared to the control in the two subsequent seasons, as net profits increased by 136.93% and 59.66% with the addition of SAP 10 g + 2.5 tonne biochar, followed by 2.5 tonne biochar + 5 tonne compost (134.42% and 57.54%) in 2021/2022 and 2022/2023, respectively. Finally, the treatment of SAP2 plus compost (T9) may be chosen as the most cost-effective treatment with the highest net return in the third season.

Table 3. Economic returns under different growing season.

Seasons	2020/2021			2021/2022			2022/2023		
Treatments	Total Cost	Total Return	Net Return	Total Cost	Total Return	Net Return	Total Cost	Total Return	Net Return
Control	1272	2189	918	2048	2450	405	1419	1911	783
SAP 1	1577	2202	625	2048	2553	508	1419	2071	942
SAP 2	1882	2474	593	2048	2771	726	1419	2256	1128
Biochar	1558	2278	721	2048	2634	589	1419	2144	1015
Compost	1509	2302	794	2048	2761	715	1419	2133	1005
SAP1 + Biochar	1863	2396	535	2048	2639	594	1419	2207	1079
SAP1 + Compost	1814	2470	657	2048	2761	715	1419	2207	1078
SAP2 + Biochar	2168	2636	470	2048	2928	882	1419	2362	1234
SAP2 + Compost	2119	2691	574	2048	3004	958	1419	2379	1250
B2.5 + Compost	1795	2567	773	2048	2994	948	1419	2362	1234
Exchange rate (1 USD = EGP)	15.75	15.76	15.76	15.75	15.77	15.77	24.59	30.93	30.93

The costs of the raw materials in 2020 were 11.75 ton compost ha⁻¹ = USD 236.67; 5.88 ton Biochar ha⁻¹ = USD 285.71; 1.60 ton SAP ha⁻¹ = USD 304.76 and 1.92 ton SAP ha⁻¹ = USD 609.52.

4. Discussion

The current study clearly demonstrated that the combined use of biochar, polymer, and compost improved soil quality and plant growth in sandy soil conditions, rather than using the single effect as performed before [34,35]. Application of SAP polymer recently showed a significant improvement in soil properties and crop production [36], but further application in different environments and soils, particularly sandy soils, is required. In the current study, the combined application of polymers, particularly at the highest rate with compost and biochar, as well as the combination of compost and biochar, showed significant improvements in sandy soil properties and crop production. Some studies showed the importance of SAP polymer in improving clay soil properties [37], reducing fertilizer loss [38], and increasing soil content of N, P, and K, which is required for the nutrient demand during plant growth and development [39,40]. Other research emphasized the value of SAP polymer in sandy soils, demonstrating that SAP polymer treatment increased soil water content [41]. However, integrating SAP polymer with other amendments has been given less attention so far, emphasizing the novelty of the current research. Here, the combined application of SAP2 polymer with either biochar (T8) or compost outperformed other single and low-rate SAP treatments in terms of improving soil physiochemical properties and bean yield and quality. This might be explained by SAP's three-dimensional, cross-linked structure, which can take in and hold as much water as 400 times its weight [42,43]. Its hydrophilic functional groups, like hydroxyl, carboxyl, amide, and sulfonic groups, have excellent adsorption and complex capacities. When the molecular chain swelled beneath the three-dimensional cross-linked structure, water moisture entered the internal network easily and formed a water-blocking layer between soil particles, which could inhibit moisture from moving from the soil surface to the atmosphere or to the rock layer of slopes, but made it move horizontally, or to the place that had little SAP. As a result, soil treated with SAP can absorb more water than untreated soil, and it also permits the water to be released gradually when the soil moisture level drops [44]. Application of SAP polymer not only increases soil water holding capacity, but also improves other physiochemical properties in the sandy soil. The chemical hydrophilic groups and network structure of the SAP hydrogel molecule may be responsible for this. The water molecules were charged by weak connections, which could result in a good water exchange between the polymer and the soil. However, combining SAP polymer with biochar or compost outperformed a single application of SAP polymer in terms of enhancing soil characteristics and crop yield. This is primarily explained by the fact that biochar decomposes more slowly in the soil than compost because it contains more stable organic carbon molecules than compost [45,46]. In contrast, the compost's

decaying organic elements promote the development of soil microorganisms and boost the activity of soil enzymes, increasing soil organic matter and improving the qualities of sandy soil [47]. This demonstrates the importance of combining compost and biochar with SAP polymer in enhancing the physiochemical characteristics of sandy soils and increasing crop production. Nevertheless, further research is required to use these combinations in different environments with summer crops rather than the current winter crop. Application of SAP polymer with compost and biochar in diverse environments, including moderate and high temperatures with summer crops, will give a realistic insight into using cost-effective amendments in improving degraded soils and crop production to accomplish food security and nutrition goals. Furthermore, the effect of these materials on soil microbial activity and greenhouse gas emissions should be considered as a future research direction. On the other hand, including these resources into decision support tools such as crop models [48] will enable them to be used at scale in a cost-effective manner.

5. Conclusions

The combination of biochar (its shelf life in the soil is 25 years) + compost (its shelf life is 3 years) led to an improvement in the biological activity of the soil, which was reflected in the chemical properties and bulk density of the soil with reduced carbon emissions. From the perspective of economic returns, the use of this mixture gave an economic return like the addition of polymers to the soil (its shelf life is from 6 to 7 years) and, thus, reduced the total costs of adding the polymers alone or in combination with other treatments. In conclusion, the treatment of SAP2 plus compost (T9) could be adopted as the best economic treatment, achieving the highest net return in the third season. However, applying these treatments to a single crop is a study restriction that necessitates more research into employing such amendments in crop rotation and on diverse crops.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/agronomy13102544/s1>, Figure S1: Residuals vs. fitted and normal Q-Q plots for seed yield model; Figure S2: Residuals vs. fitted and normal Q-Q plots for straw yield model; Figure S3: Residuals vs. fitted and normal Q-Q plots for biomass yield model; Figure S4: Residuals vs. fitted and normal Q-Q plots for plant height model; Figure S5: Residuals vs. fitted and normal Q-Q plots for seed weight model; Figure S6: Residuals vs. fitted and normal Q-Q plots for seed content of nitrogen model; Figure S7: Residuals vs. fitted and normal Q-Q plots for seed content of phosphorus model; Figure S8: Residuals vs. fitted and normal Q-Q plots for seed content of potassium model; Table S1: Statistical analysis of chemical soil properties studied after applied treatments; Table S2: Statistical analysis of physical soil properties studied after applied treatments; Table S3: Statistical analysis of faba beans yield and traits.

Author Contributions: Conceptualization, A.M.S.K. and T.H.K.; methodology, M.G.Z.; software, H.M.A.; validation, A.M.S.K., M.M.A.S. and H.M.A.; formal analysis, A.M.S.K.; investigation, A.M.S.K.; resources, M.M.A.S.; data curation, A.G. and T.H.K.; writing—original draft preparation, A.M.S.K.; writing—review and editing, A.M.S.K. and A.G.; visualization, A.M.S.K.; supervision, A.M.S.K.; project administration, A.M.S.K.; funding acquisition, A.G. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data are available upon request.

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Conflicts of Interest: The authors declare no conflict of interest.

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