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Response of Maize Yield and Nutrient Uptake to Indigenous Organic Fertilizer from Corn Cobs

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Abstract: Indonesia's corn harvest area is decreasing so that corn production is also decreasing. The use of suboptimal land can be done to increase the harvested corn area by adding nutrients with organic fertilizers. One of the organic fertilizer ingredients is corn cob waste. The aim of the study was to examine the role of corn cob fertilizer on the growth, yield and nutrient uptake of corn. The study used a completely randomized block design with one fertilization factor with six levels, namely chemical fertilizers and corn cob organic fertilizer at a dose of 2.5, 5, 7.5, 10 or 12.5 tons/ha. Corn cob organic fertilizer has met the standard as an organic fertilizer with an organic C content of 62.21% and organic matter of 85.71%, ranking it in the high category. The total nitrogen is 1.44%, total phosphate is 1.43% and total potassium is 2.17%. Corn cob organic fertilizer had an effect on the leaf area index, root length, levels of chlorophyll a and chlorophyll b, weight of 100 seeds, cob diameter and phosphate uptake. Doses of 12.5 tons/ha produced the highest changes in chlorophyll a and b, root length and phosphate uptake. Phosphate and potassium uptake correlated with plant biomass and root length. Therefore, the results of the present study suggest that corn cob organic fertilizer is able to support the growth, yield and nutrient uptake of corn in sub-optimum land. Several gaps and research priorities in soil fertility have been identified, which need to be addressed in the future.

Keywords: alfisol; phosphate uptake; potassium uptake; root length

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1. Introduction

Corn (*Zea mays* L.) is used as food, animal feed, biofuel and industrial raw materials in Indonesia and throughout the world. In 2021, the harvested corn area will be 5.5 million hectares with a corn production of 23 million tons in Indonesia. The harvested corn area in 2021 was lower than in 2018 which was 5,734,326 ha with a production of 30,055.623 tons [1]. This shows that there is a decrease in the area of agricultural land, causing production to decrease. The United Nations Department of Economics and Social Affairs estimates that crop production will need to increase by 70–100% to feed the world's 9.3 billion people by 2050 [2]. However, the potential for increasing the planted area is limited because the area of agricultural land is decreasing every year. Suboptimal land use is the main strategy to increase the planting area. Suboptimal land with high availability in Indonesia is alfisol soil. Utilization of alfisol soil for plant cultivation requires high intensification due to the low organic matter, acidic pH and low cation exchange capacity. This soil often experiences soil degradation due to its low organic matter content [3–6].

Agricultural intensification that is often done by Indonesian farmers is the provision of high inputs such as fertilizing with chemical fertilizers [7] since nutrition is a determinant in plant cultivation activities. Based on [8], corn grain yield is strongly influenced by nutrition, especially nitrogen. Corn yields decreased with decreased nutrient application [9]. In addition, the increase in grain yield was more significant with high nitrogen and phosphate inputs [10]. This is because the element nitrogen plays a role in the preparation of amino acids so that it can increase protein and corn grain yields. The challenges in maize nutrient management are the spatial variability of soil nutrient supply and plant performance and yield response to soil properties; plant growth conditions vary between fields, growth stages and years [11–13]. However, the fulfillment of nutrients with chemical fertilizers in high doses for a long period of time can increase soil hardness, nutrient imbalances and decrease organic matter so that soil fertility decreases [14]. Organic fertilizer is one way to avoid soil and environmental damage due to the long-term use of chemical fertilizers [15].

Organic fertilizers are fertilizers that mostly or wholly consist of organic materials derived from plants and/or animals that have gone through an engineering process such as composting [16,17]. Organic fertilizer made through the composting process (which can occur aerobically or anaerobically) is called compost. In efforts to improve soil quality and the sustainability of agricultural systems, organic materials such as agricultural waste can be proposed as raw materials for organic fertilizers and compost to improve soil quality and productivity [18,19]. Organic materials that can be used as compost include corn cob waste. Corn cobs are agricultural waste that has not been utilized and its availability is high. In addition, corn cobs contain 20–30% lignin, 25–35% hemicellulose and 45–55% cellulose, each of which can be converted into other biological compounds [20]. Cellulose is a carbon source that can be used by microorganisms as a substrate in the fermentation process to produce organic fertilizers [21]. Based on previous research, organic waste from agricultural activities such as *Indigofera tinctoria* used as organic fertilizer through the composting process contains high nutrients [22]. The utilization of corn cobs as compost is an effort to recycle organic agricultural waste. In addition, compost is considered a fertilizer that can improve soil structure and fertility. Based on previous research, processing organic matter through composting can increase the availability of exchangeable nutrients, namely K^+, Ca^{2+} and Mg^{2+}, so corn biomass could increase by 243% compared to mineral NPK [23]. To our knowledge, research related to the use of corn cobs as organic fertilizer and its role in the growth of corn plants has never been carried out. Therefore, this research was conducted to study the chemical content of corn cob organic fertilizer. Furthermore, it examines the role of corn cob organic fertilizer on the growth and yield of corn plants.

2. Materials and Methods

The research was carried out in Sukosari Village, Jumantono District, Karanganyar Regency, Central Java, Indonesia, precisely at coordinates S 07°38′07.01″ E 110°57′00.0″ with an altitude of 198.7 masl. The study used a one-factor Complete Randomized Block Design, namely: chemical fertilizer (nitrogen fertilizer = 350 $kg.ha^{-1}$, phosphate fertilizer = 125 $kg.ha^{-1}$, potassium fertilizer = 125 $kg.ha^{-1}$) and six doses of organic corn cob fertilizer at 2.5, 5, 7.5, 10 or 12.5 $tons.ha^{-1}$. The treatment was repeated five times. The application of the fertilizer treatment was carried out two days before planting and follow-up fertilization was carried out according to the level of treatment twice, namely 14 and 28 days after planting. The corn seeds used for planting were the corn variety Pertiwi 3. The spacing used was 75 ×20 cm with a total of 16 plants per plot. The type of irrigation used was surface irrigation with a frequency of irrigation of twice a week. Provision of water was done by flowing water between the beds.

The materials used in the manufacture of organic fertilizer on corn cobs are corn cobs, decomposer, molasses, bran, and cow dung fertilizer. The composting process was carried out in accordance with [24], namely using cow manure (1:10 ratio = 14.5 kg cow manure: 145 kg corn cobs waste), bran (1:60 ratio = 2.41 kg bran: 145 kg waste), molasses (1:3 = 511 ml molasses: 145 kg waste), and decomposer 500 ml (1:3 = 511 ml decomposer: 145 kg waste). Furthermore, all the ingredients that have been mixed were put into a storage barrel by volume. The composting process was carried out anaerobically [25]. The composting process was carried out for 52 days. Corn cob organic fertilizer was ready to be used when it has reached the quality criteria for organic fertilizer, which has a color and aroma like soil, does not feel hot or is at room temperature, and when held it will slightly curdle but remain crumbly.

The observed variables were the chemical composition of corn cob organic fertilizer, growth and yield of corn plants, and the uptake of phosphate and potassium nutrients by corn plants. Variable observations of the chemical content of fertilizers include pH, water content, C-Organic, organic matter, total and available nitrogen, total and available phosphate, and total and available potassium. The variables of plant growth observation included: plant height, number of leaves, leaf area index, root length, and chlorophyll a, b, and total content. The variables for crop yields included fresh plant weight, plant biomass, cob diameter, cob weight with husks, cob weight without husks, and weight of 100 seeds. The observation of the yield variables was carried out at harvest, which was 103 days after planting. The leaf area index was carried out in the maximum vegetative phase, 75 days after planting, using the length x width method. Chlorophyll content was analyzed when six weeks after planting. The chlorophyll content test was carried out using a spectrophotometer with a modified Arnon method [26]. The analytical method uses 80% acetone and a 645 and 663 nm wavelength on a spectrophotometer to measure the value of chlorophyll absorption. Analysis of plant phosphate was carried out in the maximum vegetative phase using a spectrophotometer. The process of preparing plant destruction samples was carried out by modifying the procedure by Friel with wet ashing using HNO_3 and $HClO_4$. The prepared solution was analyzed using a spectrophotometer at a wavelength of 400–470 nm [27]. Potassium analysis was carried out using atomic absorption spectrophotometry (AAS); this method was chosen because it complies with the ISO/IEC 17025 standard and is simple, precise, accurate, and the easiest method [28]. The process of preparing plant destruction samples was carried out by modifying the procedure by Friel with wet ashing using HNO_3 and $HClO_4$. The sample solution was analyzed using AAS at a wavelength of 766.5 nm. The data were analyzed using SPSS 22, namely the analysis of variance (ANOVA) with the F-test at 5% level and it is significant, then continued with Duncan's Multiple Distance Test (DMRT) at 5% level.

3. Results

3.1. Chemical Content of Corn Cob Organic Fertilizer

The results showed that organic fertilizer from corn cobs complied with the Ministry of Agriculture Regulation No.70/Permentan/SR.140/10/2011 regarding organic fertilizers, biological fertilizers, and soil conditioners (Table 1). Total N + P_2O_5 + K_2O of 5.04% met the standard. Corn cob organic fertilizer contains 62.21% organic carbon in the high category and meets the standards. C-Organic content is an essential factor determining the quality of mineral soil. The higher the total C-Organic content, the better the quality of the mineral soil. Organic carbon can induce phytochemical and biological changes in the soil to restore soil properties and increase soil quality [29]. High C-organic content can increase plant growth and yield because plants can absorb high levels of nutrients for optimal growth processes. In addition, the content of organic matter in corn cob fertilizer was relatively high, namely 85.71%. Organic matter content is significant for structural stability and supports biodiversity [30]. Fertilization with a high organic matter content can increase soil carbon absorption to encourage the availability of other elements such as nitrogen, phosphate, and potassium [31,32]. This research showed that the availability of nitrogen, phosphate, and potassium has met the standard for organic fertilizer.

3.2. Corn Growth

Organic fertilizers with a high content of organic matter, nitrogen, phosphate, and potassium can increase the storage capacity of nitrogen, phosphate, calcium, sulfur, and soil enzymatic catalytic activity, further promoting plant growth and yield. However, in this study, the dose of corn cob organic fertilizer did not affect plant height and the number of leaves (Table 2). These results indicate that corn cob organic fertilizer has not been able to support the growth of corn plants. This is because organic fertilizers gradually release nutrients into the soil solution [33]. According to [34], nitrogen mineralization from organic fertilizers takes 10 days and immobilization takes 20 days. In addition, phosphate mineralization takes 150 days, with a total immobilization phase from 180 to 240 days. In this case, nitrogen and phosphate are essential nutrients in physiological functions, namely plant metabolism [35]. The results showed that corn cob organic fertilizer had an effect on leaf area and root length index (Table 2). The leaf area index was higher with higher dose treatments. The dose of corn cob fertilizer of 12.5 tons/ha was able to produce the highest leaf area index with no significant difference compared to chemical fertilizer treatment. The higher the leaf area index, the higher the sunlight absorbed by the leaves [36]. This will support the process of photosynthesis which is an essential factor for plant growth and development [37]. The leaf area index is one of the biophysical properties of plants used to estimate plant biomass [38]. The leaf area index correlates with maize's morphological structure and yield [39]. The corn cob fertilizer also affected root length. The highest root length was in the corn cob fertilizer treatment at a dose of 12.5 tons/ha, namely 111.06 cm, and the lowest was in the chemical fertilizer treatment, which was only 70.93 cm (Table 2). The high organic carbon and organic matter content of corn cob fertilizer supports this increase in root length (Table 1), so that the organic fertilizer can trigger microbial activity, act as a source of energy, and increase synergistic interactions in the soil microbiome in improving soil structure. This causes plant roots to penetrate deeper into the soil layer so that the length and reach of roots becomes wider [40], further supporting plant growth and yield [18,37].

Table 1. Chemical content of corn cob organic fertilizer.

Parameter	Unit	Test Result	Standard *	Information
Water content	%	20.6	15–25	Meets the standards
pH		7.34	4–9	Meets the standards
Organic C	%	62.21	Minimum 1515	Meets the standards
Organic ingredients	%	85.71	-	Meets the standards
Total nitrogen	%	1.44	Macro nutrients ($N + P_2O_5 + K_2O$) minimum 4%	Meets the standards
Total phosphate	%	1.43		Meets the standards
Total potassium	%	2.17		Meets the standards
Nitrogen available	%	2.10	-	Meets the standards
Phosphate available	%	0.98	-	Meets the standards
Potassium available	%	1.75	-	Meets the standards
Cation exchange Capacity	(cmol/kg)	65	-	Meets the standards

* Standard according to the Ministry of Agriculture of the Republic of Indonesia (2011).

Table 2. The role of various doses of corn cob organic fertilizer on corn growth.

Treatment	Plant Height (cm)	Number of Leaves (Strand)	Leaf Area Index (cm^2)	Root Length (cm)
Chemical fertilizer	122.67	13.00 b	3.14 ab	70.93 a
Organic corn cob fertilizer at dose of 2.5 tons/ha	118.43	8.33 a	2.64 a	90.67 ab
Organic corn cob fertilizer at dose of 5 tons/ha	108.166	8.67 a	2.94 ab	95.40 ab
Organic corn cob fertilizer at dose of 7.5 tons/ha	121.67	8.33 a	2.91 ab	87.00 ab
Organic corn cob fertilizer at dose of 10 tons/ha	116.53	9.57 a	3.01 ab	96.90 ab
Organic corn cob fertilizer at dose of 12.5 tons/ha	113.67	9.33 a	3.76 b	111.06 b

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT ($\alpha = 0.05$)

3.3. Corn Chlorophyll

The results showed that the dose of corn cob fertilizer affected chlorophyll a, b, and total chlorophyll. The 12.5 tons/ha dose showed the highest amount of chlorophyll a and b (Table 3). This result is due to corn cob organic fertilizer containing high nitrogen and phosphate levels. Nitrogen supports an increase in soluble sugar in the leaves to increase the chlorophyll content [41]. Increased photosynthetic pigments in cob fertilizer treatment could be caused by improved soil structure, increased soil moisture retention capacity, and nutrient supply [42]. Based on [43], the nitrogen and phosphate content of organic fertilizers correlates with the chlorophyll content of plants. High chlorophyll content will increase the potential capacity of plant photosynthesis to support plant growth and yield from plant metabolic processes [44]. Based on [45], the element phosphate in fertilizer can increase the chlorophyll a and b content of plants. The photosynthetic performance index is an indicator to determine the yield potential of corn seeds [46]. Chlorophyll a and b were positively correlated with the photosynthetic performance index. This is supported by the role of jasmonic acid on chlorophyll which is synthesized from linolenic acid via the octadecane pathway [47]. Chlorophyll b is converted to chlorophyll an under the catalysis of chlorophyllide b reductase encoded by the non-yellow color 1 (NYC1) gene [48,49]. Based on [50], organic fertilizers can increase corn plants' chlorophyll content and grain yield by between 10 and 29%. The increase in seed yield was positively correlated with leaf chlorophyll, plant nitrogen, and phosphate uptake. The results of this study indicate that the chemical fertilizer treatment showed the lowest amount of chlorophyll a and b. The results of the study by [51] showed that the chlorophyll content in chemical fertilizer treatment is lower than in organic fertilizers with high nitrogen and phosphate levels. This is because organic fertilizer treatment can improve soil's physical and chemical properties such as soil water content (SWC), total soil organic carbon (SOC), total nitrogen (N), available phosphorus (P), and nitrate–nitrogen (NO_3-N) and ammonium–nitrogen (NH_4^+-N) cation exchange capacity compared to chemical fertilizer treatment [52].

Table 3. The role of various doses of corn cob compost on chlorophyll content.

Treatments	Chlorophyll a (mg.g^{-1})	Chlorophyll b (mg.g^{-1})	Total Chlorophyll (mg.g^{-1})
Chemical fertilizer	0.4307 a	1.117 a	1.5763 b
Organic corn cob fertilizer at dose of 2.5 tons/ha	0.4406 ab	1.0841 a	1.5339 ab
Organic corn cob fertilizer at dose of 5 tons/ha	0.4477 b	1.1191 a	1.5746 b
Organic corn cob fertilizer at dose of 7.5 tons/ha	0.4499 b	1.1974 ab	1.5394 ab
Organic corn cob fertilizer at dose of 10 tons/ha	0.4535 b	1.2265 ab	1.5228 a
Organic corn cob fertilizer at dose of 12.5 tons/ha	0.4685 c	1.3889 b	1.5474 ab

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT ($\alpha = 0.05$)

3.4. Corn Yield

Corn cob fertilizer treatment affected the weight of 100 seeds and cob diameter. The 12.5 ton/ha dose showed the highest cob diameter and weight without husks (Table 4). The weight of 100 seeds in the chemical fertilizer treatment was not significantly different from the corn cob fertilizer treatment at a dose of 12.5 tons/ha. These results indicate that corn cob fertilizer at a dose of 12.5 tons/ha has been able to meet the nutrients for the growth and development of corn plants. This was supported by the nutritional content of corn cob fertilizer (Table 1). In addition, the solid organic fertilizer produced from the composting process contains a diversity of microbes and nutrients for the soil and, when applied to corn plants, showed an effect on increasing the number of leaves, leaf area, root biomass, root length, and weight of 100 corn seeds [53]. The highest cob diameter and cob weight without husks was in the treatment of corn cob fertilizer at a dose of 12.5 tons/ha. The organic matter content supports this result by the fertilizer increasing phosphate solubility. Applying fertilizers with high phosphate content to alfisol soils can increase soil phosphate availability and make it available for plant uptake [54].

Table 4. The role of various doses of corn cob compost on corn yield.

Treatments	Plant Fresh Weight (g)	Plant Biomass (g)	Weight of 100 Seeds (g)	Cob Diameter (mm)	Cob Weight with Cornhusk (g)
Chemical fertilizer	127.91	26.62	27.97 c	44.53 ab	174.55
Organic corn cob fertilizer at dose of 2.5 tons/ha	91.63	27.78	19.02 a	42.33 ab	92.93
Organic corn cob fertilizer at dose of 5 tons/ha	95.21	25.92	19.23 a	32.23 a	94.98
Organic corn cob fertilizer at dose of 7.5 tons/ha	141.86	41.43	21.77 ab	38.80 ab	91.38
Organic corn cob fertilizer at dose of 10 tons/ha	95.13	27.20	25.22 bc	37.40 ab	93.32
Organic corn cob fertilizer at dose of 12.5 tons/ha	112.28	31.91	26.89 c	47.40 b	162.92

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT ($\alpha = 0.05$)

Based on the correlation test, plant phosphate uptake correlated with the weight of 100 seeds (Table 4). Phosphate uptake efficiency can increase crop production and productivity [55]. Plant nutrient uptake positively correlated with plant root length. Root growth exhibited a high degree of plasticity in response to nutrient availability, and the depth of fertilizer placement influenced the development and distribution of plant roots. Fertilization with high nitrogen and phosphate content can promote root growth by reducing metabolism [56]. It has a more significant number of cortical root aerenchyma and larger cortical cell sizes and increases nitrogen and phosphate uptake [57]. Furthermore, roots will synergistically increase corn seed yield and efficient utilization of nutrients throughout the plant. The decomposition of organic matter helps increase organic acids in the soil. This supports plant development, such as increasing cob diameter and cob weight. Improved phosphate uptake results in increased phosphate utilization efficiency and greater maize grain yields [58]. Plants with intensive development and short cycles, such as maize plants, require a higher amount of phosphate in solution and more rapid replenishment of phosphate than annual plants [59].

3.5. Plant Nutrient Uptake

The results showed that the dose of corn cob fertilizer had a positive effect on phosphorus uptake and no effect on potassium uptake (Table 5). The highest phosphorus absorption was in the corn cob fertilizer treatment at a dose of 12.5 tons/ha. In contrast, the lowest phosphorus absorption was in the chemical fertilizer treatment at only 0.8528 (g.plant^{-1}). There is high phosphorus content in the fertilizer so the uptake of phosphorus nutrients from corn plants is high. Increased phosphorus uptake supports the rate of photosynthesis, thereby causing an increase in root length, contract surface area, and root volume [60]. The results of this study indicate that phosphorus uptake correlates with root length (Table 6). The ability of plants to absorb phosphorus from the soil depends on root morphology and root exudate release and can be modulated by beneficial soil microbes [61]. The results of the study by [62] showed that root morphology correlates with phosphate uptake, seed yield, and biomass. Similarly, increased grain yields and nutrient uptake are associated with improved soil properties supported by organic fertilizers [55].

3.6. Correlation

Chlorophyll a and b were positively correlated (Table 6). This is supported by the role of jasmonic acid on chlorophyll which is synthesized from linolenic acid via the octadecane pathway [47]. Chlorophyll b is converted to chlorophyll a under the catalysis of chlorophyllide b reductase encoded by the non-yellow gene color 1 (NYC1) [44,49]. The results of this study showed that phosphorus uptake was correlated with root length (Table 6). The ability of plants to absorb phosphorus from the soil depends on root morphology and the release of root exudates and can be modulated by beneficial soil microbes [61]. Based on the correlation test, plant phosphate uptake was correlated with the weight of 100 seeds (Table 6).

Table 5. The role of corn cob compost dose on phosphate and potassium uptake.

Treatments	Phosphate Uptake (g.plant^{-1})	Potassium Uptake (g.plant^{-1})
Chemical fertilizer	0.8528 a	3.5354
Organic corn cob fertilizer at dose of 2.5 tons/ha	1.1456 ab	4.8206
Organic corn cob fertilizer at dose of 5 tons/ha	1.0191 ab	3.4415
Organic corn cob fertilizer at dose of 7.5 tons/ha	1.0706 ab	4.6906
Organic corn cob fertilizer at dose of 10 tons/ha	1.0411 ab	4.5381
Organic corn cob fertilizer at dose of 12.5 tons/ha	1.4339 b	5.7712

Note: Numbers followed by the same letter in the same column are not significantly different based on DMRT (α = 0.05)

Table 6. Correlation between observation variables.

	Plant Biomass	Root Length	Weight of 100 Seeds	Phosphate Uptake	Potassium Uptake	Chlorophyll a	Chlorophyll b
Plant biomass	1	0.582 *	0.403	0.725 **	0.720 **	0.100	0.084
Root length	0.582 *	1	0.170	0.658 **	0.579 **	0.075	0.065
Weight of 100 seeds	0.403	0.170	1	−0.029	−0.106	0.050	0.046
Phosphate uptake	0.725 **	0.658 **	−0.029	1	0.832 **	0.113	0.109
Potassium uptake	0.720 **	0.579 **	−0.106	0.832 **	1	0.112	0.100
Chlorophyll a	0.100	0.075	0.050	0.113	0.112	1	0.724 **
Chlorophyll b	0.084	0.065	0.046	0.109	0.100	0.724 **	1

Note: ** Correlation is significant at the 0.01 level (2-tailed), * Correlation is significant at the 0.05 level (2-tailed)

4. Discussion

The results showed that organic fertilizer from corn cobs met the standards of the Ministry of Agriculture No. 70/Permentan/SR.140/10/2011 concerning organic fertilizers, biological fertilizers, and soil enhancers (Table 1). A total N + P_2O_5 + K_2O of 5.04% already meets the standard. Corn cob organic fertilizer contains 62.21% organic C in the high category and has met the standard. Organic carbon can induce phytochemical and biological changes in the soil so that it is able to restore soil properties, increasing soil quality [29]. The content of organic matter in corn cobs fertilizer is quite high, namely 85.71%. The organic matter content is very important because it is required for structural stability and supports biodiversity [30]. Organic matter is a reserve of nitrogen and other nutrients needed by plants, so the high organic matter is able to support the availability of other elements such as nitrogen, phosphate, and potassium [63]

Organic fertilizers with high organic matter content can increase soil microbial biomass, populations of bacteria, fungi, and actinomycetes, as well as soil enzyme activity. All enzymatic activities linearly correlated with soil organic matter content [64]. Soil enzyme activity is a catalyst for the decomposition of organic matter, which is correlated with soil's physical and chemical properties [65], so high soil enzyme activity can increase root growth and plant biomass [66]. These soil microorganisms can promote plant metabolism by increasing their photosynthetic, carbohydrate, and protein processes, thereby increasing plant yields [67]. Microorganisms can increase plant growth and yield by increasing nutrient uptake [68,69]. As in this research, applying organic fertilizers at higher doses increased the uptake of phosphate and potassium.

Furthermore, organic fertilizers indirectly increase plant growth and yield. This study shows that organic corn cob fertilizer can increase the growth of roots and leaves, and increase the yield of corn plants. The application of corn cob fertilizer also affects root length. The highest root length was 111.06 cm in the corn cob fertilizer treatment with a dose of 12.5 tons.ha^{-1}, and was the lowest in the chemical fertilizer treatment at only 70.93 cm (Table 2). The root length is supported by organic fertilizers, which effectively source energy from soil microbes to improve soil structure. This allows plant roots to penetrate deeper soil layers to support plant growth and yields. Based on this study's results, root length correlated with phosphate uptake. The results of the study [60] showed that root morphology is correlated with phosphate uptake, seed yield, and biomass. Similarly, increases in grain yield and nutrient uptake are associated with improved soil properties supported by organic fertilizers [53].

The higher the dose of organic corn cob fertilizer can increase the plant area index. The higher the leaf area index, the higher the sunlight absorbed by the leaves [70]. This will support the process of photosynthesis which is an essential factor for plant growth and development [39]. The leaf area index, one of the plants' biophysical properties, is used to estimate plant biomass [9]. The leaf area index correlates with maize's morphological structure and yield [39]. Organic corn cob fertilizer can also increase the content of chlorophyll a and b. This result is due to organic corn cob fertilizer containing high levels of nitrogen and phosphate so that it can increase the availability of soil nutrients, affecting plant nutrient uptake. This supports the increase in soluble sugar in the leaves to increase the chlorophyll content [41]. Increased photosynthetic pigments in cob fertilizer treatment could be caused by improved soil structure, increased soil moisture retention capacity, and nutrient supply [71]. Based on [72], the nitrogen content of organic fertilizers correlates with the chlorophyll content of plants. In addition, the induction of organic matter in the soil can help increase the soil's organic acids, which can support plant development.

5. Conclusions

This study shows that corn cob organic fertilizer has met the standard as organic fertilizer with an organic C content of 62.21% and organic matter content of 85.71% in the high category. The total nitrogen is 1.44%, total phosphate is 1.43%, and total potassium is 2.17% with a neutral pH of 7.34. Corn cob organic fertilizer had an effect on leaf area index, root length, chlorophyll a, chlorophyll b, weight of 100 seeds, cob diameter, and phosphate uptake. The higher doses of corn cob organic fertilizer affected the increase in leaf area index, root length, chlorophyll a, chlorophyll b, 100 seed weight, cob diameter, and phosphate uptake. The nutritional content of organic corn cob fertilizer supports this. Doses of 12.5 tons/ha increased chlorophyll a and b and root length and had the highest phosphate uptake. Phosphate and potassium uptake correlated with plant biomass and root length. Therefore, the results of the present study suggest that corn cob organic fertilizer is able to support the growth, yield, and nutrient uptake of corn in sub-optimum land. Several gaps and research priorities in soil fertility have been identified, which need to be addressed in the future.

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References

1. BPS. *Indonesian Corn Production*; Central Bureau of Statistics: Jakarta, Indonesia, 2021.
2. Tian, X.; Engel, B.A.; Qian, H.; Hua, E.; Sun, S.; Wang, Y. Will reaching the maximum achievable yield potential meet future global food demand? *J. Clean. Prod.* **2021**, *294*, 126285. [CrossRef]
3. Libutti, A.; Trotta, V.; Rivelli, A.R. Biochar, vermicompost, and compost as soil organic amendments: Influence on Growth Parameters, Nitrate and Chlorophyll Content of Swiss Chard (*Beta vulgaris* L. var. *cycla*). *Agronomy* **2020**, *10*, 346. [CrossRef]
4. Baghel, V.; Thakur, J.K.; Yadav, S.S.; Manna, M.C.; Mandal, A.; Shirale, A.O.; Sharma, P.; Sinha, N.K.; Mohanty, M.; Singh, A.B.; et al. Phosphorus and Potassium Solubilization From Rock Minerals by Endophytic *Burkholderia* sp. Strain FDN2-1 in Soil and Shift in Diversity of Bacterial Endophytes of Corn Root Tissue with Crop Growth Stage. *Geomicrobiol. J.* **2020**, *37*, 550–563. [CrossRef]
5. Joy, B.; Sudirja, R.; Sofyan, E.T.; Harriyanto, R.; Mulyani, O.; Herdiansyah, G. Evaluation of soil fertility status for rice, corn, soybean on suboptimal land in West Java Indonesia. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *393*, 012030. [CrossRef]
6. Budiastuti, M.; Purnomo, D.; Setyaningrum, D. Agroforestry System as the Best Vegetation Management to Face Forest Degradation in Indonesia. *Rev. Agric. Sci.* **2022**, *10*, 14–23. [CrossRef]
7. Kiloes, A.M.; Puspitasari; Mulyono, D.; Syah, M.J.A. Land resources management of shallots farming: A case study in the highlands of Solok Regency, West Sumatera. *IOP Conf. Ser. Earth Environ. Sci.* **2021**, *648*, 012097. [CrossRef]
8. Djaman, K.; Allen, S.; Djaman, D.S.; Koudahe, K.; Irmak, S.; Puppala, N.; Darapuneni, M.K.; Angadi, S.V. Planting date and plant density effects on maize growth, yield and water use efficiency. *Environ. Chall.* **2022**, *6*, 100417. [CrossRef]
9. Song, L.; Jin, J. Improving CERES-Maize for simulating maize growth and yield under water stress conditions. *Eur. J. Agron.* **2020**, *117*, 126072. [CrossRef]
10. Zhang, W.; Xiong, Y.; Li, Y.; Qiu, Y.; Huang, G. Effects of organic amendment incorporation on maize (*Zea mays* L.) growth, yield and water-fertilizer productivity under arid conditions. *Agric. Water Manag.* **2022**, *269*, 107663. [CrossRef]
11. Liu, J.; Shu, A.; Song, W.; Shi, W.; Li, M.; Zhang, W.; Li, Z.; Liu, G.; Yuan, F.; Zhang, S.; et al. Long-term organic fertilizer substitution increases rice yield by improving soil properties and regulating soil bacteria. *Geoderma* **2021**, *404*, 115287. [CrossRef]
12. Liu, B.; Gao, P.; Zhang, S. Photosynthesis and Fine Root Growth Dynamics of Soybean in Walnut-Soybean Agroforestry System. *Comput. Intell. Neurosci.* **2022**, *2022*, 2246824. [CrossRef] [PubMed]
13. Liu, Z.; Hao, Z.; Sha, Y.; Huang, Y.; Guo, W.; Ke, L.; Chen, F.; Yuan, L.; Mi, G. High responsiveness of maize grain yield to nitrogen supply is explained by high ear growth rate and efficient ear nitrogen allocation. *Field Crops Res.* **2022**, *286*, 108610. [CrossRef]
14. Yang, F.; Shen, S.; Gao, W.; Ma, Y.; Han, B.; Ding, Y.; Wang, X.; Zhang, K. Deciphering discriminative antibiotic resistance genes and pathogens in agricultural soil following chemical and organic fertilizer. *J. Environ. Manag.* **2022**, *322*, 116110. [CrossRef] [PubMed]
15. Arifah, S.M.; Sri Budiastuti, M.T.; Dewi, W.S. Supriyadi Vermicompost formulation based on soybean husk and cow manure on shallots. *Int. J. Des. Nat. Ecodynamics* **2021**, *16*, 327–333. [CrossRef]
16. Boldrin, A.; Andersen, J.K.; Møller, J.; Christensen, T.H.; Favoino, E. Composting and compost utilization: Accounting of greenhouse gases and global warming contributions. *Waste Manag. Res.* **2009**, *27*, 800–812. [CrossRef] [PubMed]
17. Wu, S.C.; Cao, Z.H.; Li, Z.G.; Cheung, K.C.; Wong, M.H. Effects of biofertilizer containing N-fixer, P and K solubilizers and AM fungi on maize growth: A greenhouse trial. *Geoderma* **2005**, *125*, 155–166. [CrossRef]
18. Jamison, J.; Khanal, S.K.; Nguyen, N.H.; Deenik, J.L. Assessing the effects of digestates and combinations of digestates and fertilizer on yield and nutrient use of *Brassica juncea* (Kai choy). *Agronomy* **2021**, *11*, 509. [CrossRef]
19. Galsim, F.; Golabi, M.H.; Kim, Y.S.; Iyekar, C. Comparative effects of composted organic waste and inorganic fertilizer on nitrate leachate from the farm soils of northern Guam. *Int. Soil Water Conserv. Res.* **2021**, *9*, 87–102. [CrossRef]
20. Castillo-González, E.; De Medina-Salas, L.; Giraldi-Díaz, M.R.; Sánchez-Noguez, C. Vermicomposting: A valorization alternative for corn cob waste. *Appl. Sci.* **2021**, *11*, 5692. [CrossRef]
21. Liew, J.X.; Loy, A.C.M.; Chin, B.L.F.; AlNouss, A.; Shahbaz, M.; Al-Ansari, T.; Govindan, R.; Chai, Y.H. Synergistic effects of catalytic co-pyrolysis of corn cob and HDPE waste mixtures using weight average global process model. *Renew. Energy* **2021**, *170*, 948–963. [CrossRef]
22. Budiastuti, M.T.S.; Thaidy, S.; Sulistyo, T.D.; Manurung, I.R.; Setyaningrum, D. The effectiveness of organic fertilizer from natural dyes waste on the growth of *Indigofera tinctoria* L. *IOP Conf. Ser. Earth Environ. Sci.* **2022**, *1016*, 012014. [CrossRef]
23. Pandit, N.R.; Schmidt, H.P.; Mulder, J.; Hale, S.E.; Husson, O.; Cornelissen, G. Nutrient effect of various composting methods with and without biochar on soil fertility and maize growth. *Arch. Agron. Soil Sci.* **2020**, *66*, 250–265. [CrossRef]
24. Budiastuti, M.; Pujiasmanto, B.; Sulistyo, T.D.; Ike, A.; Agroteknologi, P.S.; Pertanian, F.; Maret, U.S.; Agronomi, P.M.; Pertanian, F.; Maret, U.S. Pemanfaatan Limbah Ekstraksi *Indigofera tinctoria* L. sebagai Pupuk Organik pada Usaha Batik Pewarna Alami di Sukoharjo. *PRIMA J. Community Empower. Serv.* **2020**, *4*, 109–119. [CrossRef]
25. Cucina, M.; De Nisi, P.; Trombino, L.; Tambone, F.; Adani, F. Degradation of bioplastics in organic waste by mesophilic anaerobic digestion, composting and soil incubation. *Waste Manag.* **2021**, *134*, 67–77. [CrossRef]
26. Arnon, D.I. Copper Enzymes in Isolated Chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol.* **1949**, *24*, 1–15. [CrossRef]
27. Song, Y.; Shang, W.; Wang, Z.; He, S.; Sun, Y.; Shi, L.; Shen, Y.; He, D. Functional Analysis of Glucose-6-Phosphate Translocator PoGPT1 in Embryogenic Callus Formation of Tree Peony. *Horticulturae* **2022**, *8*, 957. [CrossRef]

28. Du, J.; Chang, Y.; Zhang, X.; Hu, C. Development of a method of analysis for profiling of the impurities in phenoxymethylpenicillin potassium based on the analytical quality by design concept combined with the degradation mechanism of penicillins. *J. Pharm. Biomed. Anal.* **2020**, *186*, 113309. [CrossRef]
29. Vida, C.; de Vicente, A.; Cazorla, F.M. The role of organic amendments to soil for crop protection: Induction of suppression of soilborne pathogens. *Ann. Appl. Biol.* **2020**, *176*, 1–15. [CrossRef]
30. Paterson, E.; Sim, A. Soil-specific response functions of organic matter mineralization to the availability of labile carbon. *Glob. Chang. Biol.* **2013**, *19*, 1562–1571. [CrossRef]
31. Soria, R.; Ortega, R.; Bastida, F.; Miralles, I. Role of organic amendment application on soil quality, functionality and greenhouse emission in a limestone quarry from semiarid ecosystems. *Appl. Soil Ecol.* **2021**, *164*, 103925. [CrossRef]
32. Cai, A.; Xu, M.; Wang, B.; Zhang, W.; Liang, G.; Hou, E.; Luo, Y. Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility. *Soil Tillage Res.* **2019**, *189*, 168–175. [CrossRef]
33. Shaji, H.; Chandran, V.; Mathew, L. *Organic Fertilizers as a Route to Controlled Release of Nutrients*; Elsevier Inc.: Amsterdam, The Netherlands, 2021; ISBN 9780128195550.
34. Leno, N.; Sudharmaidevi, C.R. Physicochemical and Nutrient Release Characteristics of a Thermochemical Organic Fertilizer Produced from Degradable Solid Waste and Its Effect on Productivity of Banana. *Commun. Soil Sci. Plant Anal.* **2021**, *52*, 2562–2577. [CrossRef]
35. Naumann, M.; Koch, M.; Thiel, H.; Gransee, A.; Pawelzik, E. The Importance of Nutrient Management for Potato Production Part II: Plant Nutrition and Tuber Quality. *Potato Res.* **2020**, *63*, 121–137. [CrossRef]
36. Hosseini, M.; McNairn, H.; Mitchell, S.; Robertson, L.D.; Davidson, A.; Ahmadian, N.; Bhattacharya, A.; Borg, E.; Conrad, C.; Dabrowska-Zielinska, K.; et al. A comparison between support vector machine and water cloud model for estimating crop leaf area index. *Remote Sens.* **2021**, *13*, 1348. [CrossRef]
37. Zhang, Y.; Xia, C.; Zhang, X.; Sha, Y.; Feng, G.; Gao, Q. Quantifying the relationships of soil properties and crop growth with yield in a NPK fertilizer application maize field. *Comput. Electron. Agric.* **2022**, *198*, 107011. [CrossRef]
38. Raj, R.; Walker, J.P.; Pingale, R.; Nandan, R.; Naik, B.; Jagarlapudi, A. Leaf area index estimation using top-of-canopy airborne RGB images. *Int. J. Appl. Earth Obs. Geoinf.* **2021**, *96*, 102282. [CrossRef]
39. Shao, G.; Han, W.; Zhang, H.; Liu, S.; Wang, Y.; Zhang, L.; Cui, X. Mapping maize crop coefficient Kc using random forest algorithm based on leaf area index and UAV-based multispectral vegetation indices. *Agric. Water Manag.* **2021**, *252*, 106906. [CrossRef]
40. Zhang, J.; Bei, S.; Li, B.; Zhang, J.; Christie, P.; Li, X. Organic fertilizer, but not heavy liming, enhances banana biomass, increases soil organic carbon and modifies soil microbiota. *Appl. Soil Ecol.* **2019**, *136*, 67–79. [CrossRef]
41. Salehi, A.; Tasdighi, H.; Gholamhoseini, M. Evaluation of proline, chlorophyll, soluble sugar content and uptake of nutrients in the German chamomile (*Matricaria chamomilla* L.) under drought stress and organic fertilizer treatments. *Asian Pac. J. Trop. Biomed.* **2016**, *6*, 886–891. [CrossRef]
42. Sorkhi, F. Effect of Vermicompost Fertilizer on Antioxidant Enzymes and Chlorophyll Contents of Borago Officinalis Under Salinity Stress. *Iran. J. Plant Physiol.* **2021**, *11*, 3559–3598. [CrossRef]
43. Zafar-ul-hye, M.; Naeem, M.; Danish, S.; Khan, M.J.; Fahad, S.; Datta, R.; Brtnicky, M.; Kintl, A.; Hussain, M.S.; El-esawi, M.A. Effect of cadmium-tolerant rhizobacteria on growth attributes and chlorophyll contents of bitter gourd under cadmium toxicity. *Plants* **2020**, *9*, 1386. [CrossRef]
44. Li, Y.; Sun, Y.; Jiang, J.; Liu, J. Spectroscopic determination of leaf chlorophyll content and color for genetic selection on *Sassafras tzumu*. *Plant Methods* **2019**, *15*, 73. [CrossRef] [PubMed]
45. Jama-Rodzeńska, A.; Chohura, P.; Gałka, B.; Szuba-Trznadel, A.; Falkiewicz, A.; Białkowska, M. Effect of Different Doses of Phosgreen Fertilization on Chlorophyll, K, and Ca Content in Butterhead Lettuce (*Lactuca sativa* L.) Grown in Peat Substrate. *Agriculture* **2022**, *12*, 788. [CrossRef]
46. Ghorbanzadeh, P.; Aliniaeifard, S.; Esmaeili, M.; Mashal, M.; Azadegan, B.; Seif, M. Dependency of Growth, Water Use Efficiency, Chlorophyll Fluorescence, and Stomatal Characteristics of Lettuce Plants to Light Intensity. *J. Plant Growth Regul.* **2021**, *40*, 2191–2207. [CrossRef]
47. Fang, H.; Luo, F.; Li, P.; Zhou, Q.; Zhou, X.; Wei, B.; Cheng, S.; Zhou, H.; Ji, S. Potential of jasmonic acid (JA) in accelerating postharvest yellowing of broccoli by promoting its chlorophyll degradation. *Food Chem.* **2020**, *309*, 125737. [CrossRef]
48. Li, Y.; Song, H.; Zhou, L.; Xu, Z.; Zhou, G. Tracking chlorophyll fluorescence as an indicator of drought and rewatering across the entire leaf lifespan in a maize field. *Agric. Water Manag.* **2019**, *211*, 190–201. [CrossRef]
49. Ruan, J.; Zhou, Y.; Zhou, M.; Yan, J.; Khurshid, M.; Weng, W.; Cheng, J.; Zhang, K. Jasmonic acid signaling pathway in plants. *Int. J. Mol. Sci.* **2019**, *20*, 2479. [CrossRef] [PubMed]
50. Agegnehu, G.; Bass, A.M.; Nelson, P.N.; Bird, M.I. Benefits of biochar, compost and biochar-compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Sci. Total Environ.* **2016**, *543*, 295–306. [CrossRef]
51. Zandvakili, O.R.; Barker, A.V.; Hashemi, M.; Etemadi, F. Biomass and nutrient concentration of lettuce grown with organic fertilizers. *J. Plant Nutr.* **2019**, *42*, 444–457. [CrossRef]
52. Urra, J.; Alkorta, I.; Lanzén, A.; Mijangos, I.; Garbisu, C. The application of fresh and composted horse and chicken manure affects soil quality, microbial composition and antibiotic resistance. *Appl. Soil Ecol.* **2019**, *135*, 73–84. [CrossRef]

53. Dahunsi, S.O.; Oranusi, S.; Efeovbokhan, V.E.; Adesulu-Dahunsi, A.T.; Ogunwole, J.O. Crop performance and soil fertility improvement using organic fertilizer produced from valorization of *Carica papaya* fruit peel. *Sci. Rep.* **2021**, *11*, 4696. [CrossRef]
54. Qiu, Y.; Fall, T.; Su, Z.; Bortolozo, F.; Mussoline, W.; England, G.; Dinkins, D.; Morgan, K.; Clark, M.; Liu, G. Effect of Phosphorus Fertilization on Yield of Chipping Potato Grown on High Legacy Phosphorus Soil. *Agronomy* **2022**, *12*, 812. [CrossRef]
55. Nunes, R.D.S.; de Sousa, D.M.G.; Goedert, W.J.; de Oliveira, L.E.Z.; Pavinato, P.S.; Pinheiro, T.D. Distribution of Soil Phosphorus Fractions as a Function of Long-Term Soil Tillage and Phosphate Fertilization Management. *Front. Earth Sci.* **2020**, *8*, 350. [CrossRef]
56. Wang, C.; Wang, Y.; Yan, S.; Li, Y.; Zhang, P. Biochar-amended composting of lincomycin fermentation dregs promoted microbial metabolism and reduced antibiotic. *Bioresour. Technol.* **2022**, *367*, 128253. [CrossRef] [PubMed]
57. Chen, X.; Liu, P.; Zhao, B.; Zhang, J.; Ren, B.; Li, Z.; Wang, Z. Root physiological adaptations that enhance the grain yield and nutrient use efficiency of maize (*Zea mays* L.) and their dependency on phosphorus placement depth. *Field Crops Res.* **2022**, *276*, 108378. [CrossRef]
58. Pereira, S.I.A.; Abreu, D.; Moreira, H.; Vega, A.; Castro, P.M.L. Plant growth-promoting rhizobacteria (PGPR) improve the growth and nutrient use efficiency in maize (*Zea mays* L.) under water deficit conditions. *Heliyon* **2020**, *6*, e05106. [CrossRef] [PubMed]
59. Saia, S.; Aissa, E.; Luziatelli, F.; Ruzzi, M.; Colla, G.; Ficca, A.G.; Cardarelli, M.; Rouphael, Y. Growth-promoting bacteria and arbuscular mycorrhizal fungi differentially benefit tomato and corn depending upon the supplied form of phosphorus. *Mycorrhiza* **2020**, *30*, 133–147. [CrossRef]
60. Iqbal, A.; He, L.; Khan, A.; Wei, S.; Akhtar, K.; Ali, I.; Ullah, S.; Munsif, F.; Zhao, Q.; Jiang, L. Organic manure coupled with inorganic fertilizer: An approach for the sustainable production of rice by improving soil properties and nitrogen use efficiency. *Agronomy* **2019**, *9*, 651. [CrossRef]
61. Nacoon, S.; Jogloy, S.; Riddech, N.; Mongkolthanaruk, W.; Kuyper, T.W.; Boonlue, S. Interaction between Phosphate Solubilizing Bacteria and Arbuscular Mycorrhizal Fungi on Growth Promotion and Tuber Inulin Content of *Helianthus tuberosus* L. *Sci. Rep.* **2020**, *10*, 4916. [CrossRef]
62. Boring, T.J.; Thelen, K.D.; Board, J.E.; De Bruin, J.L.; Lee, C.D.; Naeve, S.L.; Ross, W.J.; Kent, W.A.; Ries, L.L. Phosphorus and potassium fertilizer application strategies in corn–soybean rotations. *Agronomy* **2018**, *8*, 195. [CrossRef]
63. Chehab, H.; Tekaya, M.; Ouhibi, M.; Gouiaa, M.; Zakhama, H.; Mahjoub, Z.; Laamari, S.; Sfina, H.; Chihaoui, B.; Boujnah, D.; et al. Effects of compost, olive mill wastewater and legume cover cropson soil characteristics, tree performance and oil quality of olive trees cv. Chemlali grown under organic farming system. *Sci. Hortic. (Amsterdam)* **2019**, *253*, 163–171. [CrossRef]
64. Chang, E.H.; Chung, R.S.; Tsai, Y.H. Effect of different application rates of organic fertilizer on soil enzyme activity and microbial population: Original article. *Soil Sci. Plant Nutr.* **2007**, *53*, 132–140. [CrossRef]
65. Mierzwa-Hersztek, M.; Gondek, K.; Baran, A. Effect of poultry litter biochar on soil enzymatic activity, ecotoxicity and plant growth. *Appl. Soil Ecol.* **2016**, *105*, 144–150. [CrossRef]
66. Jabborova, D.; Annapurna, K.; Paul, S.; Kumar, S.; Saad, H.A.; Desouky, S.; Ibrahim, M.F.M.; Elkelish, A. Beneficial features of biochar and arbuscular mycorrhiza for improving spinach plant growth, root morphological traits, physiological properties, and soil enzymatic activities. *J. Fungi* **2021**, *7*, 571. [CrossRef] [PubMed]
67. Wei, X.; Wu, S.C.; Nie, X.P.; Yediler, A.; Wong, M.H. The effects of residual tetracycline on soil enzymatic activities and plant growth. *J. Environ. Sci. Heal. Part B Pestic. Food Contam. Agric. Wastes* **2009**, *44*, 461–471. [CrossRef] [PubMed]
68. Khan, H.A.; Naqvi, S.R.; Mehran, M.T.; Khoja, A.H.; Khan Niazi, M.B.; Juchelková, D.; Atabani, A. A performance evaluation study of nano-biochar as a potential slow-release nano-fertilizer from wheat straw residue for sustainable agriculture. *Chemosphere* **2021**, *285*, 131382. [CrossRef]
69. Nardi, S.; Schiavon, M.; Francioso, O. Chemical structure and biological activity of humic substances define their role as plant growth promoters. *Molecules* **2021**, *26*, 2256. [CrossRef]
70. Yang, B.; Kun, D.; Han, L.; Heo, K.; Biging, G. The effects of tree characteristics on rainfall interception in urban areas. *Landsc. Ecol. Eng.* **2019**, *15*, 289–296. [CrossRef]
71. Mishra, B.; Bose, S.K.; Sangwan, N.S. Comparative investigation of therapeutic plant Withania somnifera for yield, productivity, withanolide content, and expression of pathway genes during contrasting seasons. *Ind. Crops Prod.* **2020**, *154*, 112508. [CrossRef]
72. He, Y.; Xie, K.; Xu, P.; Huang, X.; Gu, W.; Zhang, F.; Tang, S. Evolution of microbial community diversity and enzymatic activity during composting. *Res. Microbiol.* **2013**, *164*, 189–198. [CrossRef]