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Influence of Animal Manures on Carbon Mineralisation and Nutrient Availability in Calcareous Soil

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Abstract

Many studies were reported the impact of manure addition in enhancing soil fertility. However, animal manures might have different effects on calcareous soils. The effect of two different animal manure on carbon mineralisation and macronutrient availability in calcareous soils was studied. Different rates of poultry manure (PM5= 5 g kg^{-1}, and PM10= 10 g kg^{-1} soil), cattle manure (CM5= 5 g kg^{-1} and CM10= 10 g kg^{-1} soil), and an equal mixture of the two animal manures (PCM5= 5 g kg^{-1}, and PCM10= 10 g kg^{-1} soil) was investigated for 90 days. Animal manures increased CO_2–C respiration rate and cumulative CO_2-C in soils compared to untreated soils, and the highest results were observed in treatments that received 10 g kg^{-1} soil manure (PM10, PCM10 and CM10). The addition of animal manures increased available N, P, and K compared to untreated soils. Furthermore, treatments that received poultry manure alone (PM5, PM10) or in combination with cattle manure (PCM5, PCM10) contained a greater amount of available nutrients (N, P and K) when compared to soils treated with cattle manure at the same addition rate. Overall, the addition of poultry and cattle manures to calcareous soil has positive effects on macronutrient availability and carbon mineralisation.

Introduction

Calcareous soils are common in arid and semi-arid regions, affecting over 730 million hectares of soil worldwide, occupying more than 30% of the earth's surface [1]. Calcareous soils contain more than 2.5% of calcium carbonate ($CaCO_3$) that alters soil properties linked to plant growth. These soils are generally deficient in organic matter (OM) and available nutrients, including phosphorus that is the least mobile nutrient and less available for plants, compared to other nutrients [2]. High levels of carbonate minerals causes a rapid binding of the bioaccessible and mobile form of phosphate(PO_4); they form calcium phosphate minerals that is limiting the availability and mobility of PO_4 [3,4]. Other challenges present in calcareous soils are the high pH, volatilisation of nitrogen (N) fertilisers in the form of NH_3 gas, low availability of micronutrients, and the imbalance between nutritional elements such as calcium (Ca) magnesium, (Mg) and potassium (K) [5].

In the past decades, the use of synthetic chemical fertilisers had risen rapidly, and this contributed in raising agricultural productivity and reducing hunger worldwide [6,7]. Nitrogen (N) and phosphorus (P) fertiliser use rates per unit cropland area increased by 8 folds and 3 folds, respectively, since the year 1961 [8]. However, excessive application of fertilisers proven to cause environmental pollution and ecological problems such as soil acidification, water eutrophication and air pollution [9,8]. Therefore, reducing environmental pollution while ensuring the sustainability of food and energy production from farmlands is the current challenge.

Recently, there is increasing attention in using nutrient-rich manure as an appropriate soil management strategy that could reduce the use of chemical fertilisers and move toward sustainable agriculture intensification [10,11]. Manure application in calcareous soils could be a suitable strategy to preserve soil OM, improve soil physical ,chemical and biological properties, and increase crop yield through supplying nutrients to plants [12].

The significant demand for animal protein increased with the expansion of the human population. Cattle and poultry farms generate massive quantities of animal waste, which can be valuable sources of N and P for crop production [13]. Considering the potential of manure in improving soil properties, the overall objective of this study was to determine the effect of different application rates of cattle and chicken manure on (i) the carbon mineralisation (ii) the availability of macronutrient in a calcareous soil.

Materials and methods

Soil

Samples of calcareous soil were collected at 0-30 cm depth from the agricultural farm of the College of Agricultural Engineering Sciences, University of Sulaimani, Iraq. The soil samples were air-dried at room temperature and crushed thoroughly to pass through a 2-mm sieve. The soil is classified as Vertisols depend on the US soil taxonomy with silty clay loam texture (11.2% sand, 51.7% Silt and 37.1% clay). Soil had pH 7.7 (1:2.5, Soil: water suspension), 361 g kg^{-1} of $CaCO_3$, 6.1 C g kg^{-1} of OC, 0.57 g N kg^{-1} of total N, C/N ratio of 10.7:1, 461 mg P kg^{-1} of total P, 4.5 mg P kg^{-1} of available P, 0.11 g kg^{-1} of available K and EC 0.76 dS m^{-1}.

Cattle and chicken manure

Chicken and cattle manure were collected from animal farms at the College of Agricultural Engineering Sciences, University of Sulaimani, Iraq. The manures were air-dried and grounded to pass 4 mm sieve before adding to the soil, analytical data of the air-dried manures are given in Table 1.

Chemical analysis

The particle size analysis of the soil was determined according to the international pipette method [14]. The physicochemical properties of soil were determined according to standard methods [15,16]. The pH was measured using a pH meter in soil: water suspension (1:2.5). Electrical conductivity EC (ds.m^{-1}) was determined at 25°C with a glass electrode in soil extract using EC- meter. The titration method was used to determine calcium carbonate ($CaCO_3$). Total Organic matter determined using Walkley-Black, and total nitrogen was estimated using Micro-Kjeldahl methods. Available phosphorus estimated according to Olsen's method; Calcium, Magnesium, and by Versene method; flame photometer was used for estimation of sodium and potassium. The total concentrations of manure phosphorus (P), potassium (K), calcium (Ca), Sodium (Na), and magnesium (Mg) were measured after the digestion of samples in concentrated aqua regia[17].

Table 1. Chemical characteristics of animal manures.

Variables	Unit	Air-dried manure	
		Cattle	Chicken
pH (1:5)	/	7.6	7.9
Organic C	g kg^{-1}	394	438
Total N	g kg^{-1}	21.1	30.7
C/N ratio	/	18.7	14.3
Total P	g kg^{-1}	8.2	14.5
Total K	g kg^{-1}	23.2	31
Total Ca	g kg^{-1}	13.1	16.3
Total Mg	g kg^{-1}	3.9	6.7
Total Na	g kg^{-1}	1.7	2.8

Laboratory incubation experiment

An incubation experiment conducted to estimate the effects of poultry manure (PM), cattle manure (CM), and an equal (1:1) mixture of both (PM+CM) on CO_2-C respired from soils and nutrient availability. Carbon mineralisation was measured in a set of glass bottles containing 100 g of silty clay loam soil mixed with manures. Manure was added at the rates of 5 g kg^{-1} and 10 g kg^{-1} soil. Seven treatment groups were established (1) soil treated with 5 g kg^{-1} manure (PM5), (2) soil treated with 10 g kg^{-1} manure (PM10), (3) soil treated with 5 g kg^{-1} cattle manure (CW5), (4) soil treated with 10 g kg^{-1} cattle manure, (5) soil treated with 5 g kg^{-1} of equal parts poultry(2.5 g kg^{-1}) and (2.5 g kg^{-1}) cattle manure (PCM5), (6) soil treated with 10 g kg^{-1} of equal parts poultry(5 g kg^{-1}) and (5 g kg^{-1}) cattle manure (PCM10), and (7) control the untreated soil (CS). Sterilized distilled water was added to each soil mixture to bring it to 70% field capacity. The treatment mixtures were maintained at field capacity; soil moisture was adjusted when required, with distilled water at every sampling. All treatments were incubated at 30 °C in a laboratory incubator. From each treatment, three experimental replicates were used to measure CO_2-C respired. The CO_2-C respired was determined through trapping CO_2 in 15 ml glass vials containing 1 M NaOH. NaOH vials were changed with new vials containing fresh 1 M NaOH after 1, 3, 7, 15, 30, 60, and 90 days of incubation. The glass bottles were opened to allow aeration and maintain aerobic conditions. The respired CO_2-C during the incubation period was calculated by titrating the excess NaOH with standardized 0.1 N HCl after the addition of $BaCl_2$. The cumulative mineralized carbon calculated through the variation between CO_2 respired from the soil-containing manure and CO_2 respired from the untreated soil(control). Soil Inorganic nitrogen was extracted with 2M KCl as described by Keeney and Nelson (1982). Soil available P and K were measured following a method described in [19].

Statistical analysis

Statistical analysis was performed using the SPSS software (SPSS 17). Analysis of variance (ANOVA) was performed to determine the effects of the treatments on the studied parameters and means were compared using the LSD test, at $P = 0.05$

Results and discussions

CO_2–C respiration in soils

Microbial activity increased with the addition of manure to the soil due to an increase in the C-mineralisation rate was observed in all the treatments when compared to the control (Figure 1). The results also show the highest rate of CO_2–C respiration was noticed at the start of the incubation and declined within the first seven days of the experiment. The CO_2–C respiration rate from soil reached maximum one day after incubation mostly due to that the presence of easily biodegradable contents at the beginning of the experiment enhanced microbial activity. The CO_2–C respiration rate were 0.0330, 0.0815, 0.0965, 0.0972, 0.1611, 0.1411, and 0.1532 mg C g^{-1} soil day^{-1} for CS, PCM5, CM5, PM5, CM10, PCM10, and PM10 respectively. However, these rates reduced to 0.0025, 0.0050, 0.0051, 0.0054, 0.0055, 0.0058, and 0.0060 mg C g^{-1} soil day^{-1} for CS, PCM5, CM5, CM10, PM5, PM10 PCM10, and PM10 respectively. The CO_2–C respiration differences between treatments at the beginning and end of the experiment can be attributed to the different manure quantities and types that were added in each treatment. The quantity of C added to the CM10, PCM10, and PM10 were approximately twice higher than the added amount to PCM5, CM5, and PM5 and no extra C was added to control treatment. The reduction in CO_2–C respiration might be due to the activity of microorganisms that utilise the readily available C which is high at the beginning of the experiment and gradually declined over time [20,21]. The addition of manures also caused a significant increment of the cumulative CO_2–C in all treatments in comparison to control treatment.

Moreover, treatments that amended with a higher amount of manure 10g kg^{-1} (PM10, CM10 PCM10) had higher cumulative CO_2–C compared to treatments with low dose manures amendment 5g kg^{-1} (PM5, CM5, and PCM5). Several researchers attribute this to the presence of available decomposable organic compounds, and a high amount of total organic-C in animal manures that is implying an increase in OC mineralisation during manure decomposition stages [22]. Applying organic matter to soils increases easily decomposable organic compounds and improve soil nutrient status, which creates the favourable condition to soil microorganisms, consequently increasing microbial biomass and CO_2 release [21].

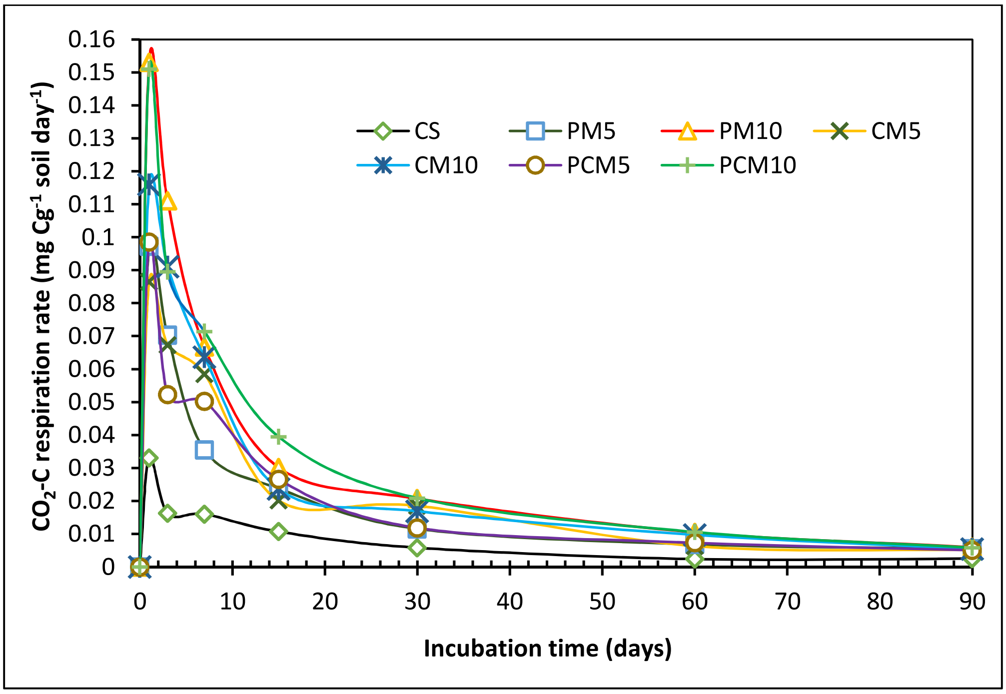

Fig. 1. Effect of poultry, cattle manure and their combination on CO_2 respiration rate at different times of incubation period.

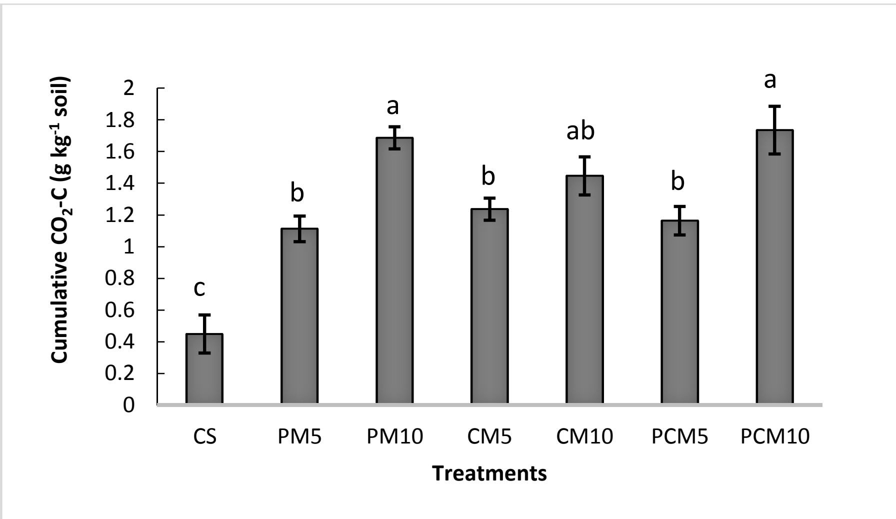

Fig. 2. Cumulative CO_2–C under different animal manure treatments. Vertical bars represent the standard deviation (n = 3), and lowercase letters indicate significant differences among the different treatments at the $P < 0.05$ level.

Inorganic Nitrogen

The amount of inorganic N in the control and untreated soils during the experiment period presented in Fig. 1. At the beginning of the incubation time (Day 1), there were no significant differences between the amended treatments with CS. However, at the end of the second week, the N mineralisation was higher in PM5, PM10 and PCM10 compared to the CS. At the end of the incubation period, all the treatments that amended with either animal manures except CM5 contained a significantly higher amount of Inorganic nitrogen in comparison to CS. Moreover, the maximum enhancement in soil N availability was found in the treatments that amended with poultry manure (PM5, PM10 and PMC10), this might be due the higher amount of nitrogen in PM since it had a narrower C:N ratio (14.3:1) comparing to CM (18.7:1). Similar results were reported that soils treated with poultry manure had a higher N mineralisation than that of untreated soil [20,21]. Although the available nitrogen in the soil increased with the increase of the manure application rates, however in this study, doubling the poultry manure rate did not double the available N in the soil. This indicates that N mineralisation depends not only on the concentration of manures but also on the composition of manures as well as the activity of the soil microbial community that mineralise and assimilate organic nitrogen[23].

Available Phosphorous

Post incubation period, the concentrations of available phosphorus in control soil and the treated soils with different manure CS, CM5, PM5, PCM5, CM10, PM10, and PCM10 were 4.7, 11.6, 15.7,13.8, 14.1, 16.8, and 14.3 mg kg^{-1} respectively. The available phosphorus in the soils was significantly increased with the addition of PM, CM and PCM (Figure 3)., Other studies have reported that the addition of organic matter can increase available phosphorus in calcareous soils that had high P-fixing capacity [12,24]. The amount of bioaccessible and mobile form of phosphate in soils is influenced by, besides the parent material mineralogical composition, the addition of fertilizers and organic matter to soils [12,4]. Increase in the available P in the manure amended soil could be attributed to that manures containing P in its composition, as well as, during organic matter decomposition, organic acids and carbonic acids will produce, and can affect surface charges and precipitation charges and increase the solubility of Ca–phosphate and Mg–phosphate precipitates in calcareous soils. Organic matter also acts as a chelating agent that coats calcium and prevent chemical reaction and precipitation with phosphorus as $Ca_3(PO_4)_2$ [21].

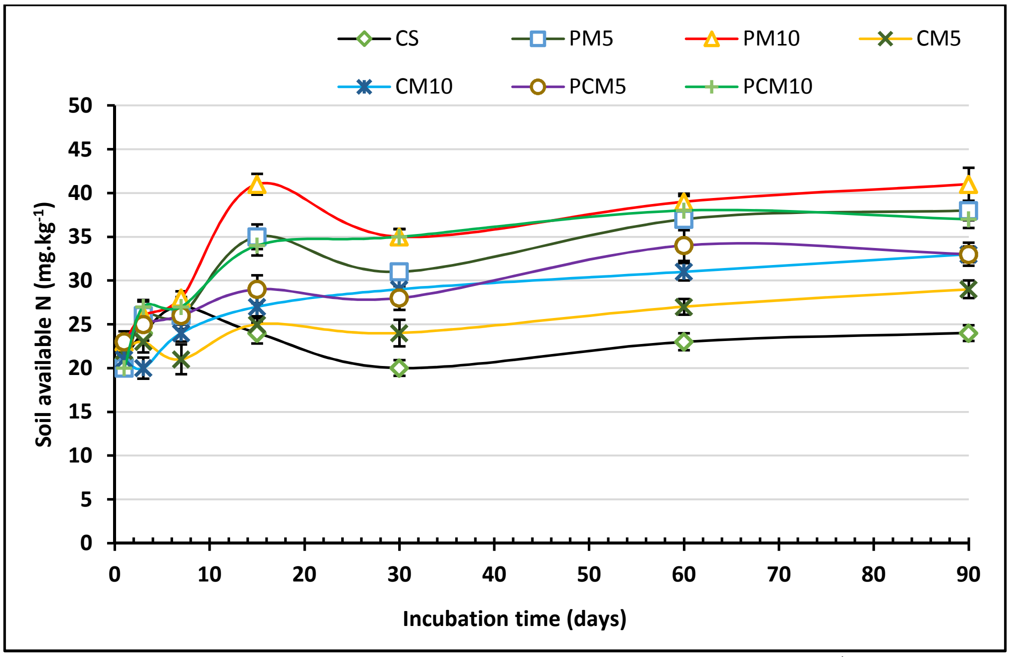

Fig. 3. Effects of different animal manure amendments on the soil availability of N (mg kg^{-1}). Vertical bars represent the standard deviation (n = 3).

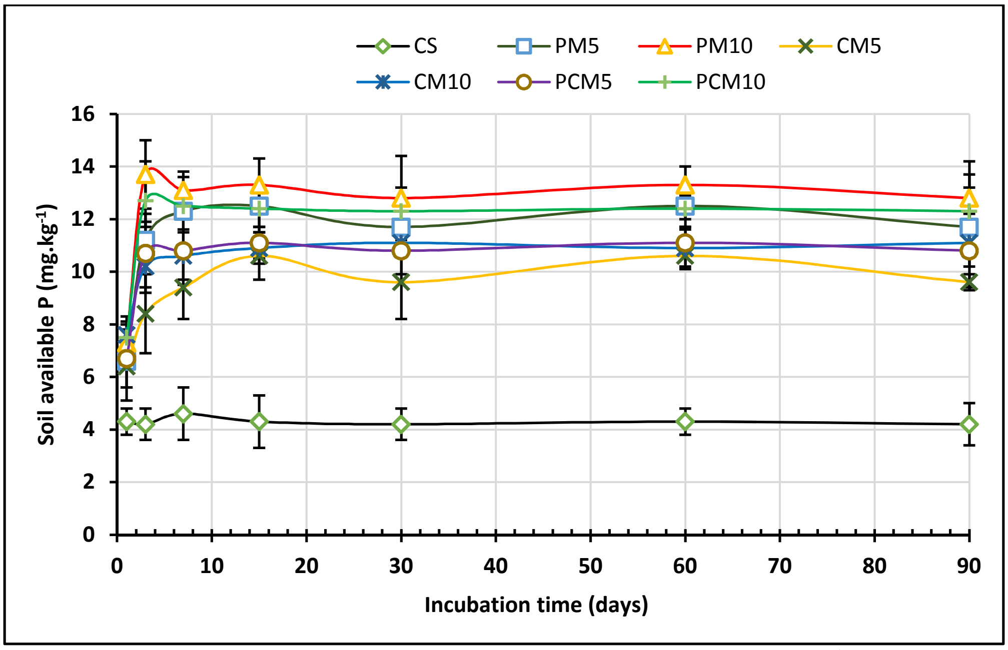

Fig. 4. Effects of different animal manure amendments on the soil availability of P (mg kg^{-1}). Vertical bars represent the standard deviation (n = 3).

Available potassium

The available potassium in soil (Fig. 4) was significantly affected by the addition of animal manures. The concentration of available K ranged from 23.6 to 32.4 mg kg^{-1} in CS, from 27.9 to 45.9 mg kg^{-1} in CM5, from 29.8 to 54.6 mg kg^{-1} in in PM5, from 35.5 to 55.8 mg kg^{-1} in PCM5, from 37.6 to 60.4 mg kg^{-1} in CM10, from 44.6 to 65.7 mg kg^{-1} in PCM10, and from 36.8 to 72.6 mg kg^{-1} in PM10. These results revealed that all the treatments had higher soil available K compared to CS. In addition, the treatments that amended with a higher dose of animal manures (CM10, PM10, and PCM10) resulted in higher available potassium in the soil. Several other researchers found that organic matter addition enhanced soil K availability [25,21]. In addition of that animal manures contain K in its composition and it releases during decomposition; manure also increases the soil cation exchange capacity (CEC) [26], which might influence the exchangeable K [25].

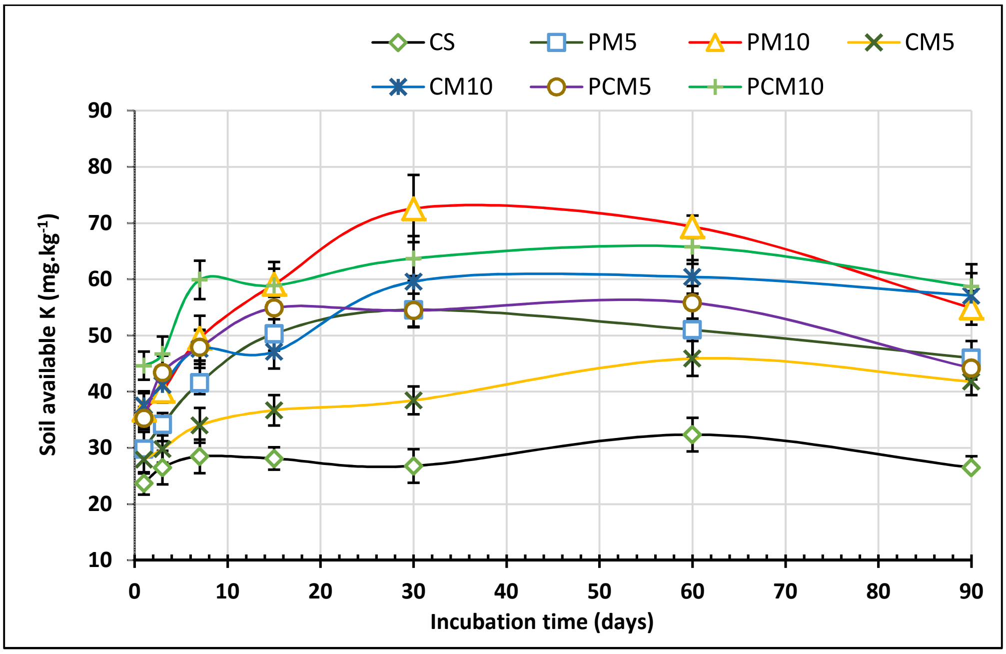

Fig. 4. Effects of different animal manure amendments on the soil availability of K (mg kg^{-1}). Vertical bars represent the standard deviation (n = 3).

Conclusions

The results indicated that animal manures (PM and CM) are suitable as soil amendments for increasing calcareous soil fertility and maintaining a higher level of available N and available P and K throughout the incubation time has added more value to the manure applications. Poultry manure was more effective in improving calcareous soil fertility compared to Cattle manure or a mixture of both manures. Moreover, although the addition of 10g kg^{-1} soil gave higher results in all the studied characteristics; however, this increase was not proportional in comparison to the 5g kg^{-1}. Manure application to calcareous soils that are low in organic matter and nutrients could be a promising approach for improving soil fertility in terms of nutrient availability more economical and sustainable.

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