

Full Length Research Paper

Nutrient release pattern from *Leptic Cambisols* as influenced by vermicompost and inorganic fertilizer applications

Molla Hadis^{1*}, Gashaw Meteke² and Wassie Haile²

¹Tigray Agricultural Research Institute, Mekelle Soil Research Center, Mekelle, Ethiopia.

²School of Plant and Horticultural Science, College of Agriculture, Hawassa University, P. O. Box 05, Hawassa Ethiopia.

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An experiment was conducted to determine the effects of vermicompost, inorganic fertilizers and their combinations on release of soil nutrients at different growth stages of wheat. A factorial combination of four levels of inorganic fertilizers (0, 33.33, 66.66, and 100% of the recommended NPK fertilizers) and vermicompost (0, 2, 4 and 6 t ha⁻¹) were laid out in complete randomized design with three replications. Soil was collected before planting and after planting (at tillering, flowering and maturity stages of wheat) from each pot in order to determine dynamics of selected nutrients (NPK). The interaction between vermicompost and chemical fertilizers were not significant for NPK contents of the soil at all growth stages except phosphorus at heading stage. In all cases, highly significant increases in total N, available P and K in the soil were observed due to the increasing rates of main effect vermicompost or inorganic fertilizers during all growing periods. The highest available as well as total contents of NPK in the soil were found at tillering stage. This initial increment at tillering stage for both factors showed a declining trend later at heading and maturity stages. However, the observed decline was in exception for vermicompost applied at 6 t ha⁻¹, which maintained highest level of available P and K and 4 t ha⁻¹ which continued mineralization of K up to heading stage. In general, application of 6 ton vermicompost per hectare was found proportional with the full dose of the recommended fertilizers in supplying NPK for wheat crop. Therefore, building up the total as well as available NPK to higher levels up to heading stage can bring maximum nutrient uptake and yields of wheat.

Key words: Growth stages, mineralization, nutrient availability, nutrient decline.

INTRODUCTION

In Ethiopia, the major constraint to agricultural growth and food self-sufficiency for a long period is the decline in soil fertility. Soil fertility is a manageable soil property and

its management is of utmost importance for optimizing crop nutrition on both a short-term and a long-term basis to achieve sustainable crop production (Roy et al., 2006).

*Corresponding author. E-mail: moheaddis@gmail.com.

In response to this problem, major efforts have been made to encourage the wider use of inorganic fertilizers. Regardless of a five times increase in fertilizer application in Ethiopia, national cereal yields have only increased 10% since the 1980s (Gete et al., 2010), while relative benefits of chemical fertilizer application have decreased over time.

Even though chemical fertilizers substantially increased the available plant nutrients during the first weeks, losses arising from different factors limit the continual supply of nutrients at critical periods where plants inquire high demand for these nutrients. Reports from Hammermeister et al. (2006) show that chemically fertilized plots declined in NH_4^+ as sampling time continues. On the other hand, available P was high at tillering which declined later at flowering and maturity stages of rice (Lungmuana et al., 2013) compared to organic residues and manures. Loss of ammonium from urea due to leaching and volatilization during two to three weeks after application (Jones et al., 2007), fixation of phosphorus with Al/Fe oxides (Lungmuana et al., 2013) and potassium with interlayer of clay mineralogy (Najafghiri, 2014) were reported after the addition of inorganic fertilizers. Such losses could exhaust the pool and available stock of certain nutrients and brought a question whether they could support plant life until the maturity stage.

However, organic farming systems with the aid of various nutrients of biological origin such as compost and vermicompost were thought to be the answers for the 'food safety and farm security' in future (Sinha et al., 2009). On the other hand, initially low levels and low release of available nutrients from organic amendments at seedling and vegetative stages can restrict uptake of adequate nutrients that might result to poor root and shoot growth of plants. Additionally, the ill effects of farmlands brought about by the application of chemical agricultural inputs for long periods in favor of boosting plant yields (Arancon et al., 2006; Sheoran et al., 2015; Sinha et al., 2009) were at a cost of inherent soil fertility and microbe inhabitants which are supposed to maintain the balance of rhizosphere by natural law.

Furthermore, NPK deficiencies are widespread and external applications are necessary to augment soil supplies for harvesting optimal crop yields while minimizing the depletion of soil nutrient reserves (Roy et al., 2006). In Ethiopia, it was reported that some crops have been suffering from deficiencies of nutrients other than nitrogen and phosphorus (ATA, 2014). This cannot be maintained in agricultural soils of the country where only NP fertilizers are applied unless supplied with organic amendments adequately like vermicasts.

Thus, evaluation of such new technologies when applied solely and/or integrated with the chemical fertilizers might give farmers another alternative to overcome such problems. At the same time, building sustainable and climate smart agriculture with vermicasts

can bring a new outlook to organic farming. Therefore, this research was conducted to investigate the effect of sole and combined applications of organic and inorganic fertilizers on the release of NPK at different growth stages of wheat.

MATERIALS AND METHODS

Area description

Soil for pot experiment was taken from farmlands of Mekan area, Enda-Mehoni district, Southern Tigray, Ethiopia. Soils having the same cropping history and soil types were sampled for potting media. According to the pedological map developed for the district, the soil type of the sampling area is Leptic Cambisols (Mitiku et al., 2007). The sampling area was located at $39^\circ 29'18''$ up to $39^\circ 33'35''$ longitude and $12^\circ 43'28''$ up to $12^\circ 46'12''$ latitude. The pot experiment was carried out at MIT Tissue Culture Micro-Propagation Laboratory's Greenhouse, Mekelle, Ethiopia.

Treatments and experimental design

Vermicompost and chemical fertilizers were used in this experiment as a source of nutrients (NPK). Vermicompost was processed by earthworm (*Eisinea fetida*) using cow manure, *Lanthana camara* leaves and wheat straw. The soil was filled to forty-eight plastic pots having 30 and 20 cm upper and bottom diameters, respectively and 28 cm depth.

A factorial combination of four levels vermicompost and four levels inorganic fertilizers (NPK) was laid out in complete randomized design (CRD) with three replications. The vermicompost levels were consisted of 0, 2, 4 and 6 t ha⁻¹ while inorganic fertilizers (NPK) were 0, 33.33, 66.66, and 100% of the recommended NPK rates. All the rates of vermicompost and NPK from inorganic fertilizers were incorporated once irrespective of the treatments and moistened at optimum. The elemental nitrogen (N), phosphorus (P) and potassium (K) was applied in the form of urea, triple superphosphate (TSP), and murate of potash (KCl) respectively. The full doses or recommended rates of NPK fertilizers were the blanket recommendation of 64 kg N ha⁻¹ and 46 kg P₂O₅ ha⁻¹ which is a common practice for cereal crops throughout the country and 60 kg K₂O ha⁻¹ respectively. The amount of Urea, TSP and KCl (g pot⁻¹) was determined by multiplying the recommended fertilizer rates (kg ha⁻¹) and 5 kg soil pot⁻¹ and divided by 2000000 kg soil ha⁻¹. Improved wheat variety; Kekaba was used as a test crop and eight seeds of wheat were planted per pot and thinned to 5 after germination to maintain enough space between plants. The moisture level was monitored regularly and maintained with distilled water.

Sampling, laboratory analysis of soils and vermicompost

Prior to planting, one composite soil sample from all soil sampling points and from the processed vermicompost was taken for routine analysis and the result is presented in Table 1. Soil sample was also collected after planting at tillering, flowering and ripening stages of wheat from each pot. The collected soil sample was air-dried, milled using pestle and mortar, sieved to pass through 2 mm diameter mesh sieve, stored and tagged in plastic bags. Then, particle size distribution, pH, EC, CEC, %OC, total N, available P, exchangeable K analyses was carried out for vermicompost and soil samples before planting and Total N (mg kg⁻¹), Av.P (ppm) and Av.K (ppm) for the successive periodic soil samples to investigate

Table 1. Initial characteristics of the soil and vermicompost used for pot experiment.

Parameter measured	Sample source	
	Soil	Vermicompost
pH	7.48	6.78
EC (ms m ⁻¹)	0.05	2.77
CEC (cmol(+) kg ⁻¹)	30.6	-
% OC	0.98	11.37
% OM	1.68	19.60
Total N (mg Kg ⁻¹)	600	14100
% Total P	-	0.78
Av P (ppm)	9.26	-
% Total K	-	1.02
Exc.K (cmol(+) kg ⁻¹)	0.34	-
% Clay	45	-
% Silt	27	-
%Sand	28	-
Textural Class	Sandy clay loam	
Moisture content (%)	-	38

the dynamics of nutrients from the above treatments. Soil texture was determined by the hydrometer method (Bouyoucos, 1962).

Soil pH and EC was determined using a pH meter from 1:2.5 soil:water ratio suspension as described in Rhoades (1982) and using EC meter from 1:5 soil water saturation extract (Jakson, 1967) respectively. The determination of soil organic carbon was based on the Walkley-Black chromic acid wet oxidation method (Walkley and Black, 1934). The Kjeldhal process (digestion, distillation and titration) as outlined by Bremner et al. (1982) was followed to determine the total nitrogen. Olsen Method (Bicarbonate extractable P) was used to extract and determine available phosphorus, using 0.5 M NaHCO₃ at adjusted pH 8.5 (Olsen et al., 1954). Determination of CEC at pH 7 was carried out with Ammonium Acetate method as described by Chapman (1965). The amount of exchangeable cations (K) in the extract was determined by flame photometer according to Gupta (2000). Available K was determined by extracting from the sample with Morgan's solution as outlined by Sahlemedhin and Taye (2000).

RESULTS AND DISCUSSION

Selected physicochemical properties of the soil and vermicompost

The textural class of the soil used for the pot experiment was sandy clay loam. According to the rating made by Tekalign (1991), the soil reaction (pH) was moderately alkaline and the organic amendment (vermicompost) was neutral. Similarly, the total organic carbon (%) and organic matter (%) of the soil was found low, whereas it was very high for vermicompost.

The cation exchange capacity (CEC) of the soil was found to be high as outlined by Hazelton and Murphy (2007). There was medium total nitrogen (%) content on the soil and very high on the vermicompost which was used as potting media according to the rating made by

Berhanu (1980) and Tekalign (1991). The total and available phosphorus content of the vermicompost and the soil was rated as very high (Murphy, 1968) and medium (Cottenie, 1980) respectively. Moreover, the total and exchangeable amounts of potassium on the vermicompost and the soil were also found to be medium (FAO, 2006), respectively.

Total nitrogen (mg kg⁻¹) content of the soil at different growth stages

The interaction between vermicompost and inorganic fertilizers was not significant for nitrogen content of the soil at all growth stages, but there were highly significant main effects ($P \leq 0.0001$). In all cases, a highly significant increase in total N of the soil was observed due to the increasing rates of vermicompost or inorganic fertilizers during all growing periods. These results were in agreement with the findings of Thakare and Wake (2015).

Out of all growth stages, the highest total N of the soil was measured at tillering stage for both main effects. At this stage, the total N was 738, 1137, 1495, 1909 mg kg⁻¹ for the pots that received 0, 2, 4 and 6 t VC ha⁻¹ (Figure 1) and 979, 1196, 1425, and 1679 mg kg⁻¹ for the pots that received 0, 33.33, 66.67 and 100% of the recommended doses of NPK, respectively (Figure 2). However, the total N (mg kg⁻¹) content for both main effects showed a declining trend from tillering to heading and maturity stages for all treatments. In that order, it declined by 23, 19, 21 and 23% for the rates of main effect vermicompost and about 30, 21, 17 and 21% for the rates of main effect inorganic fertilizers (NPK) during heading stage.

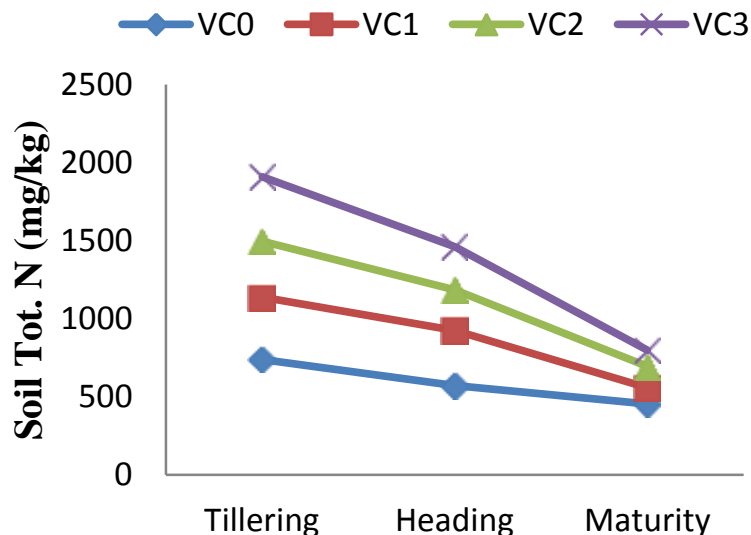


Figure 1. Total Nitrogen (mg kg^{-1}) content of the soil at different growth stages of wheat as influenced by application of different vermicompost levels.

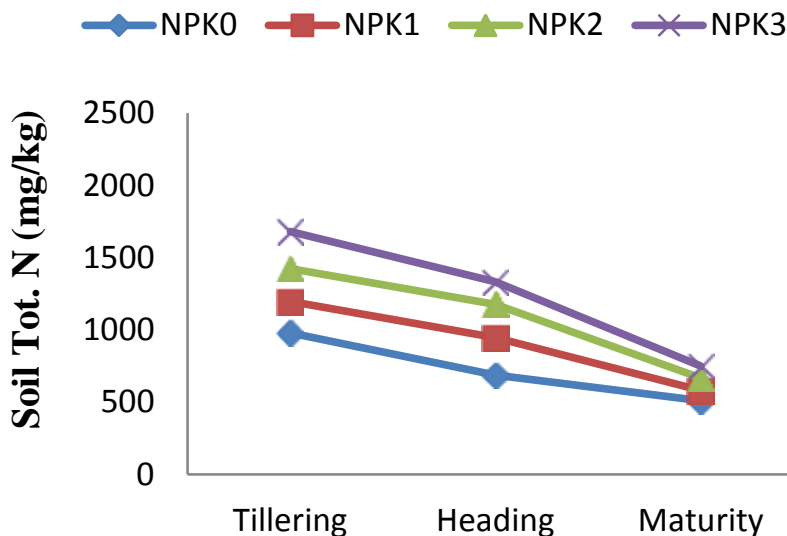


Figure 2. Total Nitrogen (mg kg^{-1}) content of the soil at different growth stages of wheat as influenced by application of different chemical fertilizer level.

Accordingly, about 39, 51, 54 and 58% of the total N measured at tillering from pots that received 0, 2, 4 and 6 t VC ha^{-1} (Figure 1), respectively were declined at maturity stage of the crop. Similarly, the declines for pots treated with 0, 33.33, 66.67 and 100% of the recommended doses of NPK from inorganic fertilizers at this stage were 48, 51, 53 and 56%, respectively. This trend has also been reported by Hammermeister et al. (2006), who reported lower soil N mineral content in the final analysis compared to the initial analysis for several treatments, suggesting loss of N with time. Similarly,

Nathiya and Sanjivkumar (2015) have also found higher available nitrogen content on vegetative and flowering stage of groundnut than at postharvest stage, indicating that plants derive nutrients from soil for their growth and development leading to the depletion of soil nutrients at the late growth stages. The decline in mineralized nitrogen with time might be related to the decrease in the labile organic matter (Tirol-Padre et al., 2007).

The temporal distribution of the total nitrogen content for the main effect chemical fertilizer had the same trend with vermicompost. The total nitrogen content was

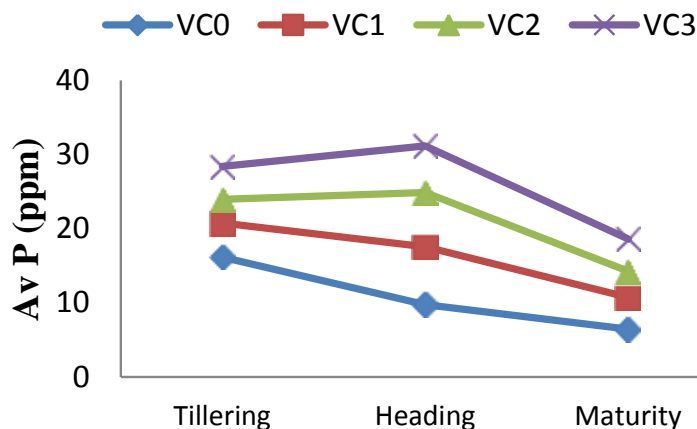


Figure 3. Phosphorus release pattern in the soil at different growth stages of wheat as influenced by application of different vermicompost levels.

increased with application levels of inorganic fertilizers at all growth stages and reached its maximum at tillering, which sharply declined at heading and maturity stages (Figure 2). Such initial increasing trend in available N after application of high rates of N from chemical fertilizer has also been reported, which later declined significantly with sampling time from tillering to heading and maturity stages of spring wheat (Lu et al., 2010).

The extent of decline in total nitrogen content from all treatment levels except the control pots was higher after heading stage of wheat for both treatment levels. At the same time, this decline was increased as the application rate of vermicompost and chemical fertilizers increased. Similar results have been reported by Lu et al. (2010) who measured an excessive N loss due to application of high N rate. In this experiment, elevated reduction with application of high N levels could be explained due to the observed higher uptake of nitrogen. Studies from Mehta et al. (1963) indicated higher nutrient uptake at the later stages of wheat, which could serve as an exception to the decline in the total N content of the soil solution. On the other hand, immobilization of nutrients explained by increases in the microbial biomass in the soils treated with vermicomposts could decline N contents of the soil and such increase in microbial biomass were greater in soils receiving higher rates of vermicompost applications (Arancon et al., 2006).

It was observed that, the average decline in nitrogen content from the experiment was relatively higher in chemically fertilized pots than for vermicompost treatments. Moreover, the relative higher amounts of total nitrogen measured at all growth stages with application of highest doses of vermicompost (6 t ha^{-1}) compared to other vermicompost and chemical fertilizer levels might be due to the higher level of initial organic carbon content (11.4%) of the vermicompost (Table 1). Similar conclusion had been made from previous studies, which

verified that changes in the organic carbon content brought about changes in the total nitrogen content of the soil (Angelova et al., 2013; Tirol-Padre et al., 2007). This investigation also showed a strong positive correlation between the total organic carbon content and the total nitrogen content with value of correlation coefficient as high as 0.97 (Angelova et al., 2013). Angelova et al. (2013) have also indicated that the considerable amount of humic acid present in vermicompost could serve as a binding site to NH_4^+ , which could prevent the possible losses through leaching and volatilization.

Phosphorus release pattern at different growth stages

Application of vermicompost and chemical fertilizers affected the availability of phosphorus in the soil. All the experimental pots treated with vermicompost and inorganic fertilizers released higher amounts of available P over the control and the availability significantly increased at all growth stages ($p \leq 0.0001$), as the application rate increases. Application of 2, 4 and 6 t ha^{-1} vermicompost gave an advantage of 28, 48 and 76% available P, respectively, over the control at tillering stages of wheat. The increase in available P due to vermicompost was in agreement with the findings of Angelova et al. (2013) and Tharmaraj et al. (2010). Generally, application of a considerable amount of total phosphorus (0.78% P in VC) (Table 1) with highest doses of vermicompost, could attribute to the elevated increase in available phosphorus irrespective of the treatment levels. After the initial increment in available phosphorus at tillering, a decline was observed at heading stage except for the higher doses of vermicompost (4 and 6 t ha^{-1}) (Figure 3). The available phosphorus content for the rates of main effect vermicompost was then decreased at

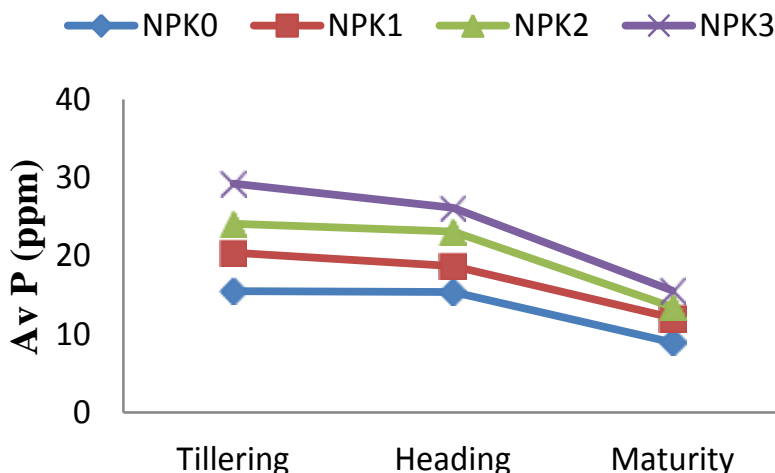


Figure 4. Phosphorus release pattern in the soil at different growth stages of wheat as influenced by application of chemical fertilizers.

maturity stage by average of 43%.

These higher doses of vermicompost continue the release of available phosphorus at tillering, maintain highest level up to heading, and then decreased at maturity by satisfying the P demand of wheat (Figure 3). Such increase on available P at mid stages of crops (mainly at vegetative and flowering) were reported by Lungmuana et al. (2013), Malik et al. (2013) and Nathiya and Sanjivkumar (2015). The increase in available phosphorus at mid stage of wheat growth might be due to the continuous breakdown of organic matter and solubilization of phosphate minerals by soil microorganisms. According to Arancon et al. (2006), the increased amounts of orthophosphates in the soil from the vermicompost-treated plots could be explained by the significant correlations between the microbial biomass N and orthophosphates, indicating that release of P was due largely to the activity of soil microorganisms.

On the other hand, application of 33.33, 66.67 and 100% NPK showed 32, 56 and 89% increments on available P contents, respectively, over the control at tillering stage (Figure 4). Unlike vermicompost, chemical fertilizers slightly decreased at heading stage and sharply reduced in available P at maturity stages. On average, a decline of 44% on available P was observed for the main effect inorganic fertilizers, at maturity. However, pots treated with highest doses of chemical fertilizers (100% NPK) have relatively higher phosphorus content (29.23 ppm) at tillering stage than vermicompost treated pots, whereas at maturity the application of highest-level vermicompost has resulted in higher available P (18.60 ppm) than did the other treatments.

The readily soluble P applied as chemical fertilizers might be exposed to P-fixation reactions in the soil, which might result in periodic decline of available P (Lungmuana et al., 2013). The decline of nutrients might

also be due to the adverse effects of chemical fertilizers on beneficial soil microorganisms and soil chemistry, which would hamper the mineralization and solubilization of P from the soil.

Potassium (K) release pattern at different growth stages

The interaction of the different levels of vermicompost and NPK fertilizer was non-significant on the release of available potassium at all growth stages. However, there were marked differences due to fertilization with either main effect on vermicompost or inorganic fertilizers. The availability of K (ppm) at all growth stages notably increased ($p \leq 0.0001$) as the application rates of vermicompost and inorganic fertilizer increased (Figures 5 and 6). The maximum available K values for the main effect of vermicompost were 386.92, 402.42 and 288.17 ppm for pots treated with 6 t ha^{-1} , while the minimum were 289.58, 254.83 and 208.17 ppm for the control treatment at tillering, heading and maturity stages of wheat, respectively. Many studies have reported that a significantly higher values of available K was obtained after the introduction of vermicompost (Angelova et al. 2013; Pankajam and Davi, 2009; Tharmaraj et al., 2010). This increase might be due to the application of a considerable amount of available K found in the earthworm processed organic matter (1.02%) (Table 1) and its solubilizing effect may result in release of available K from the soil.

The highest available K values for the chemical fertilizer applied at 100% of the recommended NPK were 407.92, 384.58 and 306.17 ppm at tillering, heading and maturity, respectively, while the respective lowest available K values of 258.50, 261.83 and 204.50 ppm

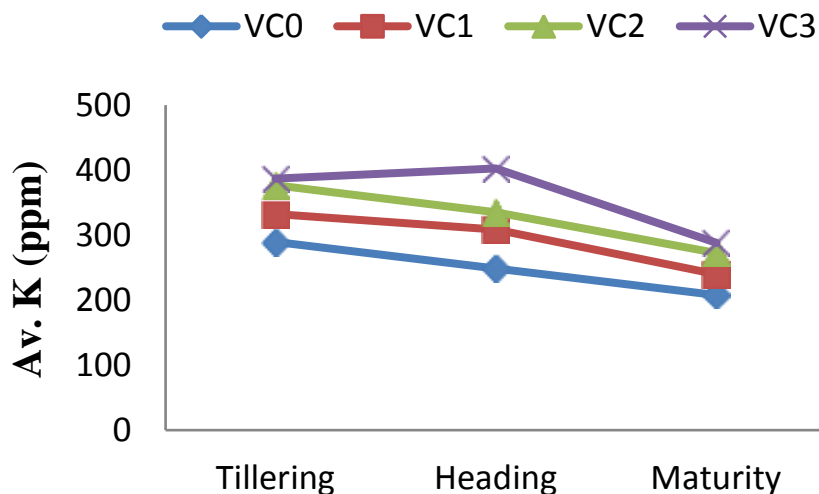


Figure 5. Potassium release pattern in the soil at different growth stages of wheat as influenced by application of vermicompost.

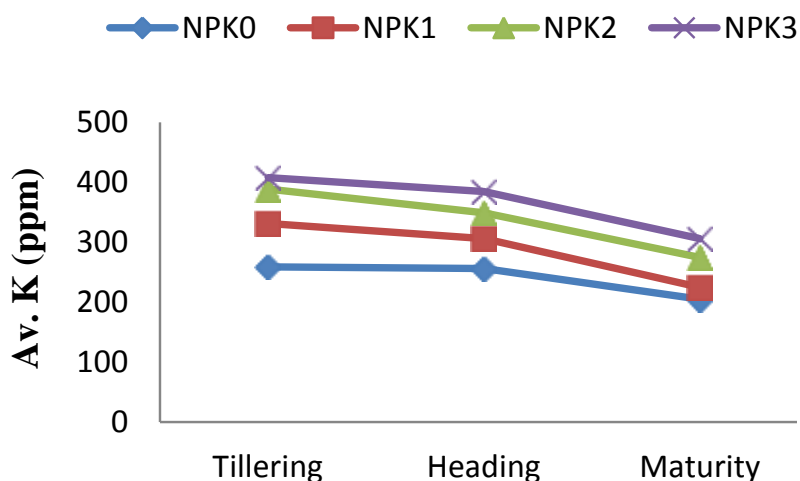


Figure 6. Potassium release pattern in the soil at different growth stages of wheat as influenced by application of chemical fertilizer.

were recorded for the control pots. However, there were no significant difference in available K between 66.67 and 100% NPK at tillering; and between 4 and 6 t VC ha⁻¹ at tillering and maturity stages of wheat. The application of vermicompost at 2, 4 and 6 t ha⁻¹ increased availability of potassium by 15, 30 and 34% over the control, respectively, at tillering stage. However, declines in available K were recorded at heading and maturity stages of wheat. This decline in available potassium was in exception for pots treated with 6 t ha⁻¹, which continue mineralization of K up to heading and then declined at maturity (Figure 5). This indicates that application of vermicompost at higher rates (6 t ha⁻¹) maintains relatively high amount of available potassium up to

heading stage. In line with this, Nathiya and Sanjivkumar (2015) have also found higher exchangeable K level at flowering stage than at reproductive and postharvest stages of groundnut.

Moreover, application of potassium from chemical fertilizer had also contributed available K to the soil solution. Applications of graded NPK showed successive increments, respectively, in available potassium contents, over the control, at tillering stage. However, the increase in available potassium due to the application of graded levels of vermicompost reached its maximum at tillering stage, which declined slightly at heading and sharply at maturity stages (Figure 5). This reduction at heading stage may possibly be due to the uptake by straw and

grain of wheat after tillering stage. Unlike vermicompost, there were no additional organic matters on chemically fertilized pots, which let wheat to be deprived only from the added nutrients and that might have resulted to the excessive decrease in available forms of potassium as the crop growth excels. Likewise, K was also correlated significantly with the availability of total organic matter (Angelova et al., 2013).

Conclusion

In general, application of inorganic fertilizers as well as vermicompost at low levels have a limited capacity in supplying NPK, which might not line up with the trend of wheat nutrient uptake. As there was no addition of Nitrogen sources after the basal application, a reduction of its total amount from all treatments were evidenced throughout the growing season. However, unlike chemical fertilizers, the higher rates of vermicompost showed a continues mineralization trend on available P and K up to heading stages of wheat, which was probably due to the activity of microorganisms along with the presence of organic matter.

Consequently, vermicompost at a rate of 6 t ha⁻¹ seems to have an equivalent release of nutrients with the recommended doses of NPK from inorganic sources. Out of all growth stages, the availability of nutrients (NPK) at tillering and heading seems to have a strong positive correlation with the uptake and yields of wheat. Hence, any soil fertility management practices that can augment the availability of nutrients after these growth stages might not have a significant contribution to the uptake as well as to the yields of wheat.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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