Int J Recycl Org Waste Agricult (2014) 3:60
DOI 10.1007/s40093-014-0060-4

ORIGINAL RESEARCH

Evaluation of vegetable wastes recycled for vermicomposting and its response on yield and quality of carrot (*Daucus carota* L.)

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Received: 28 July 2013 / Accepted: 5 April 2014 / Published online: 30 April 2014

Abstract

Background Vegetable crops generate a large amount of crop residues after harvesting of economic part. These potentially nutritious residues are soft, succulent and easily decomposable and instead of disposing or damping, it can be used as source of organic residues for utilizing the embedded nutrients through compost production. In the present study, diverse vegetable wastes were recycled for vermicomposting and their effects were evaluated in field experiments in organic carrot production.

Results The result showed that among different vegetable wastes, substrate combining mixture of non-legume and legume wastes at 2:1 emerged best considering the nutrient contents, C/N ratio, earthworm biomass and vermicompost recovery. Use of such vermicompost recorded highest root length (19.26 cm), root volume (73 cm^3), root weight (68.43 g) and root yield (16.07 Mg ha^{-1}) of carrot. The quality of the root as judged by beta carotene and total soluble solids content was also found highest by the same vermicompost.

Conclusions The findings established the potentiality of earthworm for quality vermicompost production from vegetable wastes, and through intended selection and judicious mixture of different vegetable wastes the cast quality can be improved. The study demonstrated that vermicompost produced from the substrate, combining mixture of non-legume and legume vegetable waste at 2:1 will provide the major nutrients in more balanced proportion compared to sole individual family waste vermicompost (vermicompost obtained from the waste of one single plant family). The findings can be promoted as a sound vegetable wastes recycling technology for organic carrot production to conserve natural resources and to minimize the deleterious impact of vegetable wastes on mother earth.

Keywords Vegetable wastes · Vermicompost · Carrot yield and quality

Introduction

The demand for organic vegetables is increasing day by day in domestic and international market. Carrot is highly nutritious and preferred as salad vegetable in common household. As market for organic carrot is flourishing very fast, farmers are gradually adopting organic carrot cultivation using vermicompost as organic source of nutrients. Vermicompost is the cast obtained from the ingested biomass by earthworm after undergoing physical, chemical and microbial transformations. Vermicompost contains higher percentage of available nutrients (Edwards and Burrows 1988), humic acids (Senesi et al. 1992), plant growth promoting substances such as auxins, gibberellins, and cytokinins (Krishnamoorthy and Vajrabhiah 1986), N-fixing and P-solubilizing bacteria, enzymes and vitamins (Ismail 1997). Involvement of earthworm for degradation of organic wastes promotes faster decomposition with increased rate of mineralization, humification of organic matter and increased microbial diversity that improves the quality of the final compost (Atiyeh et al. 2002). Vermicompost is preferably produced from cow dung which is

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facing scarcity due to sharp reduction in livestock population and diverse domestic use. In this context, searching for alternate substrate for quality vermicompost production has become the prime need among the organic growers.

India, the second largest producer of vegetables in the globe, produced 146.55 million tonnes of vegetables during 2010–2011 (Anonymous 2011). After harvesting the economic part, a large amount of vegetable residues remains unutilized and is dumped at roadside that creates environmental pollution in the rural areas. However, these potentially nutritious residues are soft, succulent and easily decomposable. These huge amount of otherwise unused vegetable waste may be utilized for the production of valuable vermicompost. This is essential for replenishment of plant nutrients, sustaining soil health, reducing the pollution problem and creating employment opportunities, which is being increasingly recognized as a strategy for sustainable organic farming. The present study was aimed to evaluate the suitability of vegetable wastes belonging to different botanical families for quality vermicompost preparation and to assess its influence on organic carrot production.

Materials and methods

Phase I: vermicomposting study

Experimental set up

The tank experiment on vermicomposting was conducted during March to June of 2007 and 2008 at the University farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, CoochBehar, West Bengal, India (89°23′53″E longitude and 26°19′86″N latitude). The area is characterized by high rainfall (2,100–3,300 mm $annum^{-1}$), high relative humidity, moderate temperature (minimum of 7–8 °C to maximum of 24–33.2 °C), prolonged winter with high residual soil moisture. Apart from kitchen and market wastes, vegetable residues from four different crop families and their combinations as well as cow dung were recycled for vermicompost production. Under the Solanaceae family, tomato (*Lycopersicon esculentum* Mill.), potato (*Solanum tuberosum* L.) and brinjal (*Solanum melongena* L.) crop residues were collected after harvesting of the crops. For leguminous residues, garden pea (*Pisum sativum* var. *hortense* Asch. and Graebn.), French bean (*Phaseolus vulgaris* L.) and dolichos bean (*Lablab purpureus* L.) wastes were chosen. In the Cruciferae family, unused part of cabbage (*Brassica oleracea* var. *capitata* L.), cauliflower (*Brassica oleracea* var. *botrytis* L.) and knolkhol (*Brassica oleracea* var. *gongylodes* L.) were taken and for Cucurbitaceae family, leaves and vines of bottle gourd [*Lagenaria siceraria* (Mol.) Standl.], pumpkin (*Cucurbita moschata* Duch ex Poir.) and wax gourd [*Benincasa hispida* (Thunb.) Cogn.] were collected.

Treatment details

There were 10 treatments laid out in complete randomized design with three replications. The treatments were T_1—wastes from Solanaceae family; T_2—wastes from Leguminosae family; T_3—wastes from Cruciferae family; T_4—wastes from Cucurbitaceae family; T_5—wastes from Solanaceae, Leguminosae, Cruciferae and Cucurbitaceae family at 1:1:1:1 ratio; T_6—wastes from non-legume and legume family at 1:1 ratio; T_7—wastes from non-legume and legume family at 2:1 ratio; T_8—kitchen wastes; T_9—vegetable market wastes; T_{10}—sole cow dung (control).

Vermicomposting

To prepare vermicompost for the treatments T_1–T_9, the collected vegetable wastes were finely chopped to 5 cm pieces and were allowed to pre-decompose aerobically for 15 days in cemented tank of 50 dm^3 volume by mixing with cow dung at 1:1 ratio on a weight basis. Then, 500 numbers of adult *Eisenia fetida* were introduced individually into 40 kg of pre-decomposed biowastes for the treatments T_1–T_9 and 40 kg cow dung for the treatment T_{10}. Turning was given at 15 days interval for five times and intermittent sprinkle of water was done to keep the substrate moist enough (~60 % moisture level) without stagnation of water at the bottom. The maturity of vermicompost was determined by observing physical condition and sustained nutrient level. After around 80 days, the feed materials were converted to odorless loose granular structure. The cast was collected and prepared for nutrient analysis. The total earthworm biomass and vermicompost recovery from each treatment were recorded during harvesting of vermicompost.

Chemical analysis of vermicompost

Vermicompost from different treatments was analyzed for elemental nutrient content and results were expressed on dry percentage basis. The organic carbon was estimated using rapid titration method (Walkley and Black 1934). The total nitrogen was determined using modified micro Kjeldahl method (Jackson 1967). Total phosphorus was measured calorimetrically as outlined by Page (1982). Total potassium was estimated with the help of flame photometer as suggested by Jackson (1967).

Statistical analysis

Two years data were collected and subjected to statistical analysis. The data for individual year were used and combined analysis of variance was calculated using Complete Randomized design (CRD). The treatment means were compared using least significant difference (LSD) test at 0.05 level of significance (Gomez and Gomez 1984).

Phase II: evaluation of different vermicompost on yield and quality of carrot

Experimental set up

The field experiment was conducted at the University farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, CoochBehar, West Bengal, India during November to February of 2007–2008 and 2008–2009. The soil was sandy loam (61, 20, 18 % sand, silt and clay, respectively) with pH 5.71. The initial soil organic carbon was 0.83 % and available N, P and K contents were 154.28, 21.17 and 124.48 kg ha^{-1}, respectively. The field was thoroughly ploughed and friable beds were prepared. Vermicompost obtained from different treatments of experiment 1 was incorporated to the plots at 5 Mg ha^{-1} (fresh weight basis) in two equal splits (2.5 Mg ha^{-1} per split) first as basal and second after 45 days of emergence to study their effect on carrot growth, yield and quality. The experiment was laid out in completely randomized block design with three replications. Carrot seeds (cv. Early Nantes) were sown on 15th November for both the years by ridge and furrow method with a row spacing of 30 cm. The gross plot area was 3.6 m × 2.2 m. One light irrigation was given just before sowing for quick emergence of seedlings. The extra plants within a row were thinned out after 2 weeks of germination to maintain the 10 cm spacing between the plants. The crop was raised adopting standard cultural practices.

Recording of observation

Composite soil samples from the multiple locations of the experimental plots were collected from 0 to 30 cm depth before the experiment and were analyzed for the determination of the organic carbon (Walkley and Black 1934), available nitrogen (modified micro Kjeldahl method-Jackson 1967), available phosphorus (Bray's No.1 method-Jackson 1967) and available potassium (ammonium acetate method-Jackson 1967). To record different growth, yield and quality attributes of carrot (Table 1), the plants were uprooted at marketable maturity stage from the ear marked area of 3 m × 2 m leaving two boundary rows. When the roots attain 1.8 cm or more in diameter in the upper end it is considered maturity and plot wise harvesting was done. The observations were recorded on ten randomly selected plants from each plot. The root yield was calculated from the weight of the ten randomly selected plants of the plots and multiplied by optimum plant population in 3 m × 2 m area. Root volume was measured by water displacement method. The quality of roots was assessed by estimating the beta-carotene content of the carrot root following the method suggested by Srivastava and Kumar (2002), and the total soluble solids (TSS) present in root juice were measured using Erma Hand Refractometer (0°–32° B scale) (ERMA, Japan).

Statistical analysis

Two years data were collected and subjected to statistical analysis. The data for individual year were used and combined analysis of variance was calculated using Complete Randomized Block Design (RCBD). The treatment means were compared using LSD test at 0.05 level of significance (Gomez and Gomez 1984).

Results and discussion

Nutrient composition of different vermicompost

The nutrient composition of different vermicompost (Fig. 1) varied according to the initial substrates used for decomposition. Organic carbon (OC) concentration reduced significantly during decomposition irrespective of the substrates used. However, reduction in OC was higher where the legume was present individually or in combination. Kale (1998) reported that in the decomposition process part of the carbon was transformed into carbon dioxide and was partially lost to generate energy for decomposition. Raghavendra and Bano (2001) also observed that chemical composition of the waste influenced the rate of OC mineralization. The total nitrogen (N) concentration increased after final decomposition and the highest N concentration was observed in legume wastes which may be due to higher initial N concentration in legume wastes (1.58) than other families. Among the mixture of different family wastes, N content increased significantly with the increase in the proportion of legume waste. Gaur and Singh (1995) also stated that the nitrogen enrichment pattern depends on the quality of the substrate material particularly the initial nitrogen present in the wastes and the extent of decomposition. There was considerable reduction in C/N ratio of the substrates at the end of decomposition due to loss in carbon. Gajalaksmi and Abbasi (2002) also pointed out that the organic carbon lost as carbon dioxide in the process of respiration increases the concentration of nitrogen ultimately resulting in decreased C/N ratio of the substrate. The overall variation in total phosphorus (P) was also significant in all the treatments and the concentration of phosphorus varied according to initial P concentration of the substrate. However, the legume-based substrate showed higher P concentration over the others. Vinotha et al. (2000)

Table 1 Growth, yield and quality of carrot as influenced by different vermicompost

Treatments	Plant height (cm)	No. of leaves plant^{-1}	Days to maturity	Root length (cm)	Root diameter (cm)	Root volume (cm^3)	Root weight (g)	Root yield (Mg ha^{-1})	TSS (°Brix)	Beta carotene (mg 100 g^{-1})
T_1	30.50	10.39	97.00	16.42	2.43	65.88	58.18	12.72	7.39	2.94
T_2	34.19	10.70	91.00	15.47	2.29	60.91	52.26	10.35	7.16	2.61
T_3	28.34	7.14	102.00	12.24	2.02	59.18	48.34	9.67	7.10	2.23
T_4	29.19	8.72	100.00	14.51	2.24	63.23	54.19	11.38	7.24	2.58
T_5	30.42	10.21	95.00	15.76	2.41	64.91	56.24	11.54	7.34	3.04
T_6	31.49	11.12	94.00	16.87	2.57	67.26	60.29	13.11	7.47	3.11
T_7	31.96	12.37	92.00	19.26	3.48	73.00	68.43	16.07	7.96	3.28
T_8	32.12	12.84	93.00	18.43	3.21	69.41	65.21	14.62	7.83	3.21
T_9	26.32	6.49	104.00	11.12	1.84	56.91	44.21	8.19	6.92	1.87
T_{10}	32.76	14.27	88.00	17.82	2.96	67.82	64.13	14.17	7.74	3.16
LSD (0.05)	3.81	1.51	6.32	3.38	0.19	6.15	5.36	0.64	0.44	0.37
CV %	9.42	6.89	10.23	4.58	3.47	9.84	7.79	5.13	4.26	3.82

Treatments T1 to T10 were the vermicompost prepared from different vegetable wastes of the experiment1

LSD least significant difference, *CV* coefficient of variation

reviewed that phosphorus solubilizing microorganism enhances the phosphatase activity during decomposition resulting in greater mineralization and increases the P concentration in the final vermicompost. The total potassium (K) was also increased significantly at the end of decomposition. Although the initial K concentration was highest in the Cruciferae family K improvement in sole Cruciferae was 9 % only, whereas legume waste mixed with wastes of other family the K concentration was higher. Thus, the highest K concentration with 16 % improvement in final vermicompost was recorded in the non-legume and legume waste at 2:1 ratio. Interestingly, among the mixed composition, legume added in higher ratio increased the final K concentration of vermicompost which may be due to the improvement in decomposition process. Kaviraj and Sharma (2003) opined that acid production by the microorganisms is the major mechanism for solubilizing insoluble potassium at the time of decomposition.

Earthworm biomass and vermicompost recovery

The experimental results (Fig. 2) showed that differences in the composition of substrates affected the survival and reproduction of earthworm during the period of vermicomposting. A significant increase in earthworm biomass was observed in all the substrates at the end of decomposition. The gain in earthworm biomass (8.40 times over initial) and vermicompost recovery (19.63 kg) were faster in sole cow dung culture. This could be attributed to carbon rich and microorganisms loaded growth medium that encouraged easy decomposition and faster multiplication of earthworms. Interestingly, among the different crop families, solanaceous wastes started with the initial C/N ratio of 26.05 had achieved the maximum earthworm biomass (2.65 kg) with 5.30 times multiplication over initial. Whereas legume waste started with lowest C/N ratio (20.02) recorded comparatively lower earthworm biomass (2.15 kg) with 4.30 times multiplication over initial. The C/N ratio might have affected the decomposability, earthworm multiplication and amount of compost recovery. Gaur (1999) pointed out that for maximum microbial decomposition the minimum stable C/N ratio should be around 25–30:1. The result further showed that among the mixed family waste (vermicompost obtained from the waste of different families under study), the non-legume and legume waste at 2:1 ratio recorded the maximum earthworm biomass (3.20 kg) and vermicompost recovery (15.60 kg). The different family mixed waste might have provided relatively soft, succulent and palatable feeding materials that encouraged the multiplication of earthworm as well as decomposition of substrates. It may be noted that predetermined mixture of legume with other families rather than the sole legume wastes was beneficial for quality vermicompost production and higher recovery of cast. Among the natural mixed wastes (vermicompost obtained from mixed vegetable waste from different families as obtained from the kitchen or market), kitchen wastes (3 kg earthworm biomass and 14.32 kg finished cast) showed better performance over market wastes. Edward (1998) stated that the quality of organic wastes is one of the prime factors which determine the onset and rate of earthworm reproduction. He also pointed that the substrates rich in organic carbon and other nutrients with relatively narrow C/N ratio as well as good moisture holding capacity enhances the earthworm multiplication and cast production. Suthar (2007) also found that substrates that are easily decomposable and have more available nutrients will be

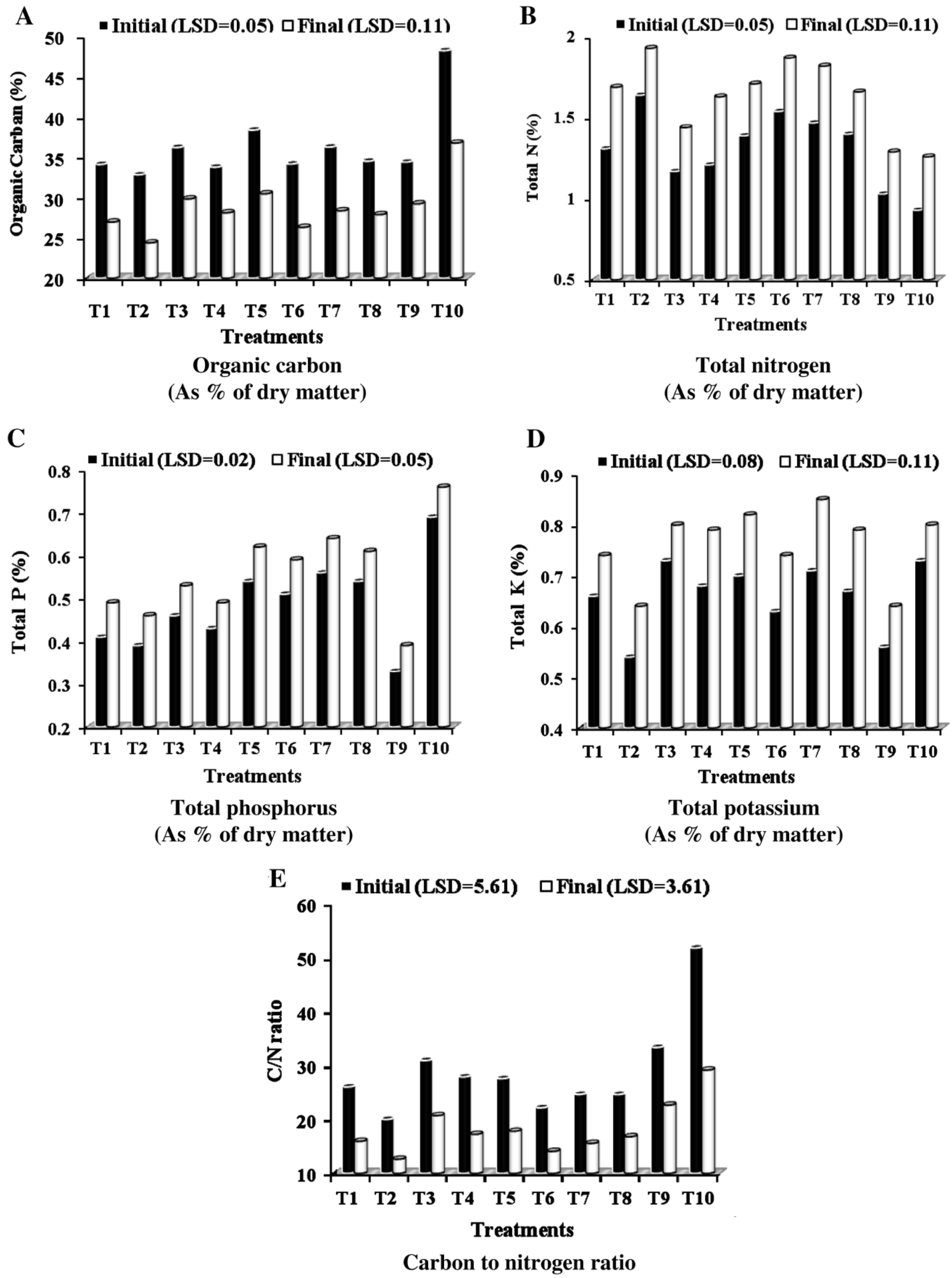

Fig. 1 **a–e** Initial and final concentration of organic carbon, total nitrogen, total phosphorus and total potassium as well as changes in C/N ratio, as affected by different substrates (treatment details are given in the text)

more acceptable to earthworm. The lower multiplication rate and vermicompost recovery in cruciferous and cucurbitaceous crop wastes could be due to the presence of glycoalkaloids sinigrin and cucurbitacin, respectively, that might have restricted the feeding, multiplication and production of vermicompost by the earthworm.

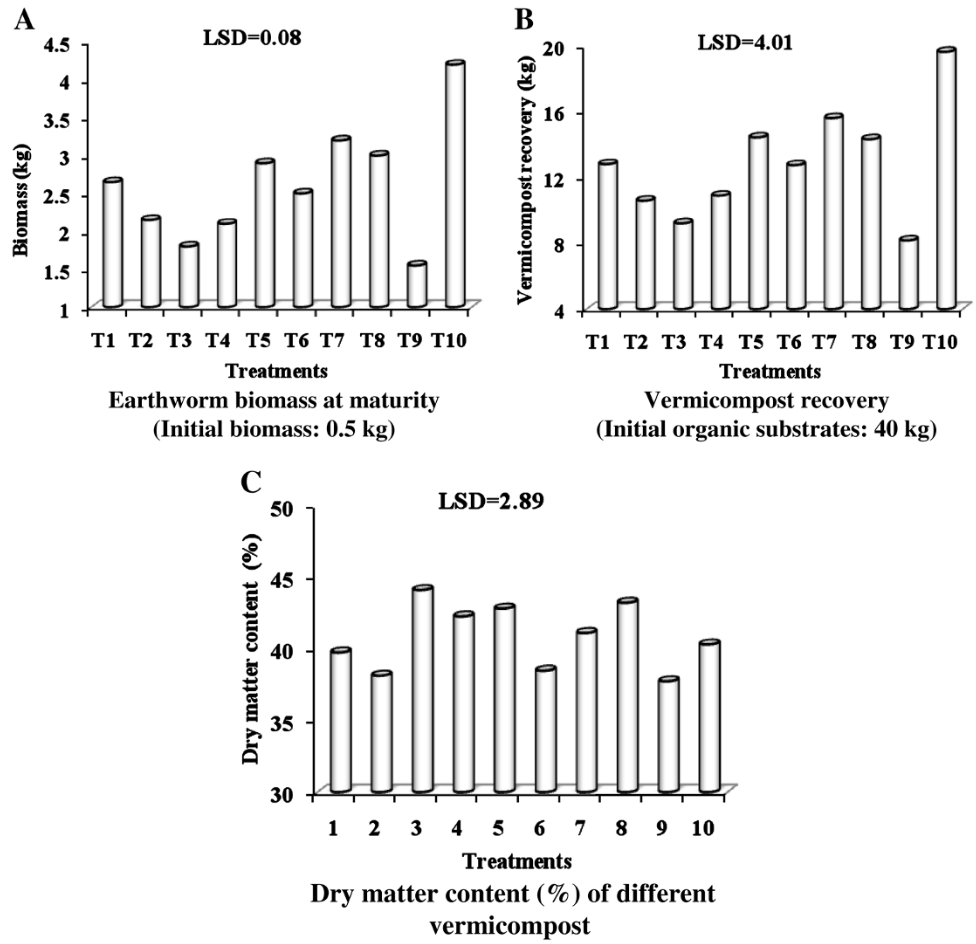

Fig. 2 **a–c** Earthworm biomass, vermicompost recovery and dry matter content (%) of different vermicompost at maturity as affected by different substrates (treatment details are given in the text)

Response of different vermicompost on carrot

The result revealed that vermicompost had significant and positive response on different growth parameters of carrot (Table 1). Application of vermicompost prepared from sole legume waste recorded the maximum plant height (34.19 cm), but number of leaves (14.27 plant^{-1}) was highest in sole cow dung vermicompost. The days taken for root maturity of carrot were also found minimum (88 days) for the control. The treatment comprising of vermicompost prepared from non-legume and legume waste at 2:1 ratio emerged as best growth medium in terms of superior yield and quality attributes with maximum root length (19.26 cm), root volume (73 cm^3) and root weight (68.43 g) as well as beta carotene (3.28 mg 100 g^{-1}) and TSS content of the root (7.96°Brix). As a culmination of favorable effect of major yield components, the highest root yield (16.07 Mg ha^{-1}) was recorded by the same treatment. Vermicompost carried high levels of soil enzymes and plant growth hormones which enhanced microbial populations and held more nutrients over longer periods (Ndegwa and Thompson 2001). Padmavathiamma et al. (2008) opined that addition of vermicompost improved soil environment and encouraged proliferation of roots that drew more water and nutrients from larger area. The positive response of vermicompost on plant growth and yield was probably not only due to the available nutrients but also due to the availability of plant growth influencing materials, such as growth regulators, humic acids produced by the microbial population resulting from earthworm activity (Arancon et al. 2004). Carrot is underground root vegetable and enlargement of primary root depends on the availability of nitrogen and potassium nutrients. Nitrogen is directly involved in chlorophyll synthesis and transportation of photosynthates to the developing roots. The deficiency of nitrogen results in poor foliage growth and thin plant which prevents normal photosynthesis and growth of plant leading to smaller roots. Whereas, potassium played vital role for translocation of sugar and bulking of root and inadequate K prevents sugar and starch accumulation and results in poor root growth. Vermicompost produced from judicious mixture of non-legume and legume family waste provided maximum P and K and reasonable concentration of nitrogen and supplied the elements throughout the growth phases of the plant that might have fulfilled the demand of the crop and encouraged better root growth and yield compared to other vermicompost.

In traditional practices, farmers through their innovative ideas try to produce vermicompost from different organic wastes such as kitchen waste, market waste etc., but composition of nutrients in such natural mixture of wastes varies from place, season, human choice etc. It is difficult to predict the quality of final cast. In our experiment, we have shown the family wise recyclability of different vegetable wastes. Through predetermined selection and judicious mixture of different vegetable wastes, the vermicompost quality can be improved to supply the nutrients in a more balanced form that can fulfill the requirement of the crop nutrient demand.

Conclusions

The findings established the potentiality of earthworm for quality vermicompost production from vegetable wastes. However, sole cow dung culture has emerged highly suitable substrate for vermicomposting considering earthworm biomass and cast recovery. Keeping in mind the decreasing livestock population and the scarcity of cow dung, vegetable waste can act as a potential substitute for cow dung where cow dung can be used as a starter material rather than sole growth medium. In organic vegetable cultivation, the emerging challenge is to supply the major nutrients through organic sources. The study demonstrated that by predetermined selection and judicious mixture of different vegetable wastes, the cast quality can be improved. The substrate combining mixture of non-legume and legume vegetable waste at 2:1 ratio provided the major nutrients in more balanced proportion compared to others. The findings can be promoted as a sound vegetable wastes recycling technology for organic vegetable production to conserve natural resources and to minimize the deleterious impact of vegetable wastes on mother earth.

Acknowledgments All the authors duly acknowledge the technical and financial support from the University Uttar Banga Krishi Viswavidyalaya.

Conflict of interests The authors declare that they have no competing interests.

Authors' contributions RC is the main and corresponding author who has conceived the ideas of this work. SB was involved in data recording, interpreting and editing the manuscript. JCJ was the supervisor of the work. All the authors have read and approved the final manuscript for submission to this journal.

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