Int J Recycl Org Waste Agricult (2017) 6:203–218
DOI 10.1007/s40093-017-0168-4

ORIGINAL RESEARCH

Vermicompost and vermiwash as supplement to improve seedling, plant growth and yield in *Linum usitassimum L.* for organic agriculture

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Received: 27 January 2017 / Accepted: 7 June 2017 / Published online: 26 June 2017

Abstract
Purpose To study the organic production in two varieties of *Linum* (Linseed) crop using different proportions of vermicomposts and combination of vermiwash as an environment friendly substitute to chemical fertilizers for organic farming of Linseed.
Method Vermicompost prepared from cattle dung was mixed in different proportions, i.e. 0, 20, 40, 60, 80, and 100% vermicompost v/v with soil and commercial potting media (Perlite, Peat and Coconut coir). To study the germination, vegetative growth, reproductive growth and yield in two varieties of *Linum usitassimum L.* LC-54 and LC-2063 were grown in a polyhouse for a 2 years trial. A total of 960 seedlings and 240 plants were studied for assessment of result in 24 treatments. Additional treatments with foliar application of 1:1 v/v vermiwash and recommended dose of inorganic fertilizer were done to determine and compare the role of vermicompost, vermiwash and inorganic treatment.
Results Substituting soil with 60% (v/v) vermicompost in LC-54 and with 40% (v/v) vermicompost in LC-2063 improved the performance of seeds, root morphology and stem growth. Life cycle of crop was shortened in two varieties of Linseed raised under different treatments of vermicompost and vermiwash. Performance of LC-54 was better at 60% and that of LC-2063 was at 40%, which can be attributed to their genotypic differences. Vermicompost proportion above 60% was of no use at any stage of life cycle in both the varieties of *Linum*. Germination and yield were further improved when foliar application of vermiwash was integrated with vermicompost for nutrient management when compared with recommended chemical fertilizer treatment and control.
Conclusion Bio-efficacy of vermicompost and vermiwash for production of organic Linseed crop has been well established with enhanced yield.

Keywords Agriculture · Earthworm · Linseed · Organic farming · Plant growth · Vermicompost

Introduction

Organic foods have recently gained importance in developed, as well as developing countries with the growing awareness about adverse effects of agricultural chemicals on human health. Demand for organic food has increased worldwide which has led to increased interest in organic agriculture (Follet et al. 1981; Sinha et al. 2009). Crops with a label of 'organically grown' fetch much higher value to farmers in domestic and international market (Lim et al. 2015; Crowder and Reganold 2015). Organic agriculture also promotes ecological conservation due to sustainable use of natural resources (Reganold et al. 1993; Letourneau and Goldstein 2001; Mäder et al. 2002). In cultivation of organically grown crops, chemical usage is excluded at all stages so organic agriculture broadly provides the dual benefit of soil quality improvement and chemical free

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organic foods (Gomiero et al. 2008). Currently many studies are being done to establish vermicompost as one of the preferred organic substitute to chemical fertilizers (Sinha and Valani 2009; Adhikary 2012). During vermicomposting, earthworms carry out the non thermophilic transformation of organic waste with the accelerated microbial decomposition and humification (Atiyeh et al. 2001). Vermicomposting being a biotechnological extension of composting, produces harmless, simple and stable organic end product, i.e. vermicompost.

There has been tremendous research focussing on the effects of vermicompost on soil condition and plant growth (Atiyeh et al. 2000a, b; Gutiérrez-Miceli et al. 2007; Singh et al. 2008; Roy et al. 2010; Joshi et al. 2013, 2015). Many studies have reflected the great potential of vermicompost in horticultural and agricultural practices in field or as a substitute in medium for plant growth in greenhouses and nurseries. Various studies have confirmed the beneficial effects of vermicompost on seed germination, seedling growth and plant productivity, but the effect of vermicompost has been unique and specific on various plant species and varieties, so it becomes utmost important to investigate the genus specific suitability of the vermicompost before its beneficial effects are predicted for a crop plant (Roy et al. 2010). Even the same rate or ratio of vermicompost application has shown different effects on different varieties of same plant (Zaller 2007; Lazcano and Domínguez 2010).

India is among top five countries producing Linseed, with U.K and Canada being top two countries, and still India imports Linseed. In India, currently Linseed occupies 468.0 thousand ha with productivity of 3490 hectogram's/ha (www.pdkv.ac.in). Linseed is an oilseed crop grown mainly in Punjab (India) in regions of Gurdaspur, Jalandhar, Hoshiarpur and Ropar. Recent statistics show that Linseed has a production of 0.1 thousand tonnes in Punjab state with average yield of 8.0 quintal per hectare. There is a scope to increase the covered area and yield of cultivating Linseed in India (Table 1).

Linseed (*Linum usitassimum L.*) belongs to the family Linaceae. It is an herbaceous plant grown in winter season in India as a Rabi crop and is sown in first fortnight of October. It grows well in drained silt loamy to clayey soil. Crop is ready for harvest in April. Linseed is the oldest oil and fibre yielding crop. Every part of, Linseed plant has commercial value (Jhala and Hall Linda 2010). The characteristics of Linseed plant are given in Table 2. The present study was designed to establish the practices in organic Linseed farming with following objectives (a) to reveal the impact, suitability, efficacy of vermicompost application on the growth and productivity potential of two regional varieties of a commercially important medicinal plant *Linum usitassimum* (b) to optimise the application rate of vermicompost considering genotype differences of each variety of foresaid oilseed crop (c) to compare the effect of vermicompost and inorganic fertilizer on growth and yield of Linseed (d) to study impact of integrating vermiwash with vermicompost as integrated nutrient management (INM) on Ontogenic development, i.e. seed germination and seedling growth in soil mix and in commercial potting media mix (d) to know positive effect on seedling and vegetative growth, if any, is congruently shown on reproductive growth of *Linum* plants in terms of flowering, fruiting and seed setting in various treatments.

Table 1 Recent data on Linseed production in major countries

Country	Years	Area (ha)	Yield (hg/ha[a])	Production (in tonnes)
Canada	2014	620,800	14,054	872,500
	2013	422,100	17,311	730,700
U.S	2014	122,220	13,234	161,750
	2013	69,610	12,247	85,250
India	2014	284,000	4965	141,000
	2013	338,000	4339	147,000
U.K	2014	15,000	26,000	39,000
	2013	34,000	18,235	62,000

Data sourced from http://faostat3.fao.org/download/Q/QC/E

[a] hg/ha—hectograms per hectare

Table 2 Characteristics of the *Linum usitassimum* (Linseed) plant

Characteristics of a Linseed plant	
Plant height	30–120 cm
Root system	Slender, shallow tap root with many lateral roots in top 30 cm of the soil
Leaves	Narrow, small, alternate leaves on stem
Stem	Narrow and thin, branched from base
Leaf shape	Oval with blunt apex
Inflorescence	Terminal panicle that bears numerous flowers
Flower	Perfect with 5 petals, 5 sepals, 5 stamen undergoes self pollination
Fruit	Globular capsule with 5 locules
Seeds	Flat shiny small seed of brown colour

Materials and methods

Procurement of *Linum* seed, vermicompost and vermiwash

Certified seeds of two varieties of *Linum usitatisimum,* i.e. LC-54 (LV_1) and LC-2063 (LV_2) were procured from Punjab Agricultural University (PAU), Ludhiana (Punjab),

Table 3 Physico-chemical properties of vermiwash, vermicompost and soil

Parameter	Vermiwash (mg/L)	Vermicompost	Soil
pH	6.12	7.11	8.6
N[a]	0.5	2.5	0.12
K[a]	1.2	8.0	4.2
P[a]	0.8	8.4	0.9
Ca[b]	130.0	240	149.9
Mn[b]	0.01	0.09	0.008
Cu[b]	0.04	5.0	0.87
Zn[b]	0.9	24.5	1.1

[a] Values are in g/kg

[b] Values are in mg/kg for vermicompost and soil

India. Both are lodging resistant varieties of Linseed. LC-54 (LV_1) is a latest release with brown seeds and white flowers and is recommended in Punjab, Himachal Pradesh, Jammu & Kashmir and Haryana. LC-2063 (LV_2) is high yielding tall variety with golden brown bold seeds, profuse branching, and blue flowers. Both the varieties have average life cycle of 160 days.

Vermicompost prepared from cattle dung was procured from Mahavir Farm, Phillaur, and Punjab. Vermiwash was prepared by earthworm secretion, siphoned as the seepage drain from the worm bed and was kept in earthen pots. 100 ml Vermiwash was diluted with water to prepare (1:1 v/v) foliar spray. Soil was taken from the land which was not cultivated since 5 years.

Physico-chemical properties of vermicompost, vermiwash and soil were analysed for pH, Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), and heavy metals (Mn, Cu, Zn). pH, was measured using PCSTestr 35 series Digital meter. Nitrogen was estimated by the method of Bremner and Mulvaney (1982). Method of John (1970) was used for measuring phosphorus. Potassium and calcium were analysed by Systronics Flame Photometer-128. Heavy metals analysis was also measured by method of APHA (2012) using AAS Thermofisher iCE 300. Physico-chemical characteristics of vermicompost, vermiwash and soil are given in Table 3.

Experimental site

The experiment was conducted at Department of Horticulture, Jalandhar Cantt, Punjab (India) with Latitude/longitude: 31°38′11″N 74°52′29″E and at altitude 218 m above mean sea level. The mean maximum and minimum temperatures were 45.5 and 4 °C, respectively. The mean annual rainfall is 649 mm, distributed over 120 rainy days. Relative humidity range was 78–96%.

Experimental lay out

Experiment was set up at a polyhouse in germination trays and pots for 2 years trial during Oct–April 2014–15 and 2015–16. Seeds of both the varieties were hand sown in mid October.

Germination trays

To determine the germination indices for twelve replicates of six treatments, vermicompost (v/v) was mixed in different proportions 0% (G_0), 20% (G_{20}), 40% (G_{40}), 60% (G_{60}), 80% (G_{80}), and 100% (G_{100}) with soil. To understand and compare the impact of vermiwash and inorganic fertilizer, two more treatments were set up, i.e. 50% vermicompost (v/v) supplemented with foliar spray of vermiwash (G_{vw}) and inorganic treatment (G_{inor}) to the soil. To compare the effectiveness of vermicompost in substituting commercial potting media, eight more treatments were prepared, i.e. vermicompost was mixed with commercial media in proportion of 0, 20, 40, 60, 80 and 100% in treatments G_{CM0}, G_{CM20}, G_{CM40}, G_{CM60}, G_{CM80} and G_{CM100}. In treatment G_{CMvw}, vermicompost and commercial media mix was supplied with vermiwash and in G_{CMinor}, chemical fertilizer was applied and germination trays were filled with 20 ml of mixed substrate as per treatments in Table 4. Composition of commercial media consisted of 35% limed peat moss, 35% perlite and 30% coconut coir, procured from a local nursery. Totally, 16 treatments with 12 replicates were used for germination studies. Seed germination and seedling growth were studied up to 5 weeks after sowing seeds in germination trays. Plant sampling was done at 21 days after sowing (DAS), for morpho-physiological studies, and five randomly selected seedlings from twelve replicates of all the 16 treatments were uprooted from germination trays having vermicompost and soil mix; vermicompost and commercial potting mix. At 35 DAS, all the seedlings under treatment in cell plug trays were uprooted for study. To obtain the sample, the root was cut from the root collar and watered with gentle deionised water spray using a sieve below to collect any broken fragment. Root was immersed in graduated cylinder to calculate the root volume. Same sample was used to measure length, fresh and dry root weight. Shoots were also measured for shoot length and fresh shoot weight. Samples were then oven dried at 70 °C to determine the respective dry weights.

Potting studies for complete life cycle

Plantation was done in earthen pots of volume 9.5l (15 cm diameter and 10 cm height) and placed in polyhouse in a complete randomized design with eight treatments in three

Table 4 Proportion of vermicompost, soil, and commercial potting media substituted vol/vol in treatments of germination and pot culture to study life cycle of *Linum*

Treatments for germination studies by substituting soil with vermicompost			Treatment for germination studies by substituting commercial potting media with vermicompost			Treatment for vegetative and reproductive growth by substituting soil with vermicompost in pot culture		
Treatment	Proportion of vermicompost (%)	Soil and additive (%)	Treatment	Proportion of vermicompost (%)	Commercial potting media (%)	Treatment	Proportion of vermicompost (%)	Soil and additive (%)
G_0	0	100	G_{CM0}	0	100% commercial potting media	P_0	100	0
G_{20}	20	80	G_{CM20}	20	80% commercial potting media	P_{20}	80	20
G_{40}	40	60	G_{CM40}	40	60% commercial potting media	P_{40}	60	40
G_{60}	60	40	G_{CM60}	60	40% commercial potting media	P_{60}	40	60
G_{80}	80	20	G_{CM80}	80	20% commercial potting media	P_{80}	20	80
G_{100}	100	0	G_{CM100}	100	0% soil + 0% commercial potting media	P_{100}	0	100
G_{vw}	50	50% soil + vermiwash foliar spray	G_{CMvw}	50	50% commercial potting media + vermiwash foliar spray	P_{vw}	50	50% soil + vermiwash foliar spray
G_{inor}	0	100% soil + inorganic fertilizer	G_{CMinor}	0	100% commercial potting media + inorganic treatment	P_{inor}	0	100% soil + inorganic fertilizer

replicates (Table 4). INM (Integrated Nutrient Management), was done in three treatments (G_{vw}, G_{CMvw} and P_{vw}) by combining use of foliar spray of vermiwash with vermicompost application. A comparison of growth parameters was made among plants under inorganic fertilizer treatment, vermicompost treatments, vermiwash treatment and unamended soil. Separate heaps of soil and vermicompost were made, sieved and mixed so as to make vermicompost application dose to be 0, 20, 40, 60, 80 and 100% (Arancon et al. 2004; Zaller 2006) for treatments P_0, P_{20}, P_{40}, P_{60}, P_{80} and P_{100}. In another two treatments, 50% vermicompost application was integrated with vermiwash (P_{vw}) and inorganic fertilizers (P_{inor}). Four seeds per pot were sown at 5 cm depth. After emergence, seedlings were thinned to two plants per pot. The plants were irrigated, according to the plant water requirement, so as to maintain the moisture up to 60%. Manual weeding was done intermittently. 100 ml of Vermiwash mixed with water (1:1 v/v) was applied fortnightly for first 50 days to the seedlings and then monthly to plants in P_{vw}. Five seedlings from three replicates were randomly selected from pots and uprooted at 35 DAS. At 50 DAS no sample was destroyed and only the features above ground were studied. At 160 DAS, i.e. at the end of life cycle all the plants were uprooted and used as sample for the studies. Phenology of the plants was studied to evaluate the effect of treatments on length of life-cycle of Linseed.

Crop was hand harvested twice. First harvest was done on 128 DAS when 90% of the capsules turned brown and capsule number was counted, second harvest was on 150 DAS. Estimation of unripe green capsule, which would be available for second harvest, was also done. Ratio of ripened to unripened capsules was calculated to know early ripening. Yield (%) in first harvest was calculated to find uniformity in maturity timings. Also the ratios of marketable to non-marketable fruits were also calculated (Atiyeh et al. 2000b) so as to know the effect of different treatments on marketable seed yield. In each of the harvest, malformed and non-marketable fruits were sorted out and counted.

Measurement of plant growth index

Seedling growth is an important indicator for survival and growth of plantlings in field (Thompson 1985).

Morpho-physiological parameters

Test plants both from germination trays and potting experiments were studied. Seedling emergence was assessed daily for allometric growth, up to 35 days after sowing (DAS). Morpho-physiological parameters for shoot length, root length, seedling height, shoot weight, root weight, fresh biomass, dry biomass and root collar diameter were assessed. Branching ratio and biomass accumulation were also studied at 21 and 35 days after seed sowing (DAS). At 50 DAS Plant height stem length and basal area, and dried leaf weight was determined. Plant biomass, root: shoot ratio (by weight) and biomass allocation were also calculated. Dry weight of 50 leaves was taken to estimate photosynthetic productivity with each treatment. Fifty leaves per plant were washed in distilled water, put in paper bags and oven dried at 60 °C for 48 h. Shoot height was measured from root collar to the apex at various DAS. Stem diameter was measured as average taken at three points—slightly above the root collar, apex and median with a calliper. Stem length was taken from the soil level to the apical meristem of plant. First day of branching, flowering, fruiting, seedfill and seed maturity were noted. By submerging roots in a measuring cylinder filled with water, root volume (cm^3) was measured. Plant samples were dried in oven at 70 °C for 48 for dry weight of shoot and root. At 160 DAS, Plant height, weight, capsule number per plant, capsule weight, number of seeds per capsule and seed weight per plant was taken. Marketable yield was calculated by rejecting malformed fruits which were without rattling sound. Mean capsule weight was calculated from total fruit weight of each treatment. Fruits were thrashed to obtain seeds. Data was pooled from all replicates to calculate average yield per plant.

Germination indices

Total germination (Final germination percentage-G) and T_{50} It is most widely used index and shows germination capacity of seeds under specific treatment.

$$G = \frac{N_T \times 100}{N},$$

where N_T is proportion of seeds germinated at each treatment for last time; N is total number of seeds used.

$T_{50} = T_{50}$ is the number of days or time when half of the total seeds have germinated (Josep and Maria 2002).

Speed of emergence (S.E) Speed of germination considers the number of seeds germinated between two exposure times

$$\text{S.E} = (N_1 \times 1) + (N_2 - N_1)\frac{1}{2} + (N_3 - N_2)\frac{1}{3} + \ldots\ldots (N_n - N_{n-1})\frac{1}{n};$$

where Proportion of germinated seeds observed at first, second, third……… (n – 1), (n) days or hours (Bradbeer 1988; Wardle et al. 1991).

Germination index (G.I)

$$\mathrm{G.I} = \frac{\mathrm{RSG\%} \times \mathrm{RRG\%}}{100},$$

where RSG is relative seed germination in percentage; RRG is relative root growth in percentage (Zucconi et al. 1981; Tiquia 2010).

$$\text{Relative seed germination (R.S.G) \%} = \frac{N_{\mathrm{GT}} \times 100}{N_{\mathrm{GC}}},$$

where N_{GT} is no. of seeds germinated in treatment; N_{GC} is the no. of seeds germinated in control (Tiquia 2010).

$$\text{Relative root growth (R.R.G) \%} = \frac{\mathrm{Rl_T} \times 100}{\mathrm{Rl_C}},$$

where $\mathrm{Rl_T}$ is mean root length in treatment; $\mathrm{Rl_C}$ is mean root length in control.

Seedling vigour index (S.V.I) S.V.I $= \frac{\mathrm{Sl} \times G\%}{100}$ where Sl is seedling length and G is Total seed germination in percentage (Abdul-Baki and Anderson 1973).

Branching ratio (B_R)

It is the ratio of total number of plants and number of plants having branches. Branching ratio of 1:1 shows that all plants in a given treatment have started developing branches at a given time.

$$\text{Branching ratio } (B_{\mathrm{R}}) = \frac{N}{N_{\mathrm{B}}},$$

where N is total no. of plants; N_{B} is no. of plants having branches at a given time.

Yield indices

Fruit weight/100 capsule

$$\frac{W_{\mathrm{TNF}} \times 100}{N_{\mathrm{TF}}},$$

where W_{TNF} is weight of total number of fruits obtained from a treatment; N_{TF} is total number of fruits obtained in same treatment.

Harvest index (H.I) Harvest index (H.I) is the ratio of economic yield and biological yield taken in percentage.

$$\text{For this H.I was calculated as } = \frac{W_{\mathrm{f}} \times 100}{W_{\mathrm{s}}},$$

where W_{f} is the fruit weight (economic yield) and W_{s} (biological yield) is weight of dry stem (Donald and Hamblin 1976).

Statistical analysis

Experiment was run in triplicate and One-way ANOVA was used to calculate the differences among various treatments. Tukey's test at a level of 5% of probability was applied between different treatments. Student's paired *t* test was applied to evaluate differences between two varieties of plants. Statistical analysis was done with the help of Assistat 7.7 beta version and Minitab version 14.0 computer software programs.

Results and discussion

Comparison of germination indices in different treatments with vermicompost, commercial potting media (CPM) and vermiwash

All the treatments G_{40}, G_{60}, G_{80}, G_{100}, and G_{vw}, supported the total seed germination when compared with control and G_{inor}. Even the low dose of vermicompost application in soil has improved the total seed germination in G_{20} by 13.8% in $\mathrm{LV_1}$ and 37.8% in $\mathrm{LV_2}$, whereas 13.1 and 15.4% increase was observed in both varieties in G_{CM20} (Fig. 1). There was a significant difference ($p < 0.05$) between two varieties of plants when treated with soil and commercial media mixed with vermicompost. The 20% dosage of vermicompost when mixed in soil reduced half time of germination up to 58% in $\mathrm{LV_1}$ and 37% in $\mathrm{LV_2}$ and further increase in vermicompost dosage showed no improvement in seed germination.

Speed of seedling emergence (S.E) in different treatment showed significant differences ($p < 0.05$) for both the varieties when compared with vermicompost (G_{60}, G_{80}, G_{100}), vermiwash (G_{vw}) and inorganic fertilizer (G_{inor}) but showed no significant difference ($p > 0.05$) within soil treatment of two varieties. Speed of seedling emergence was highest in G_{60}, G_{CM20} in $\mathrm{LV_1}$ (8.8) and G_{CM20}, G_{40} in $\mathrm{LV_2}$ (8.5). Usage of foliar spray of vermiwash in Combination with 50% vermicompost have further shown qualitatively healthy early maturing seedlings, it can be attributed to availability of higher nitrogen content (Chaoui et al. 2003). Relative root growth in both the varieties increased with increasing proportion of vermicompost in soil, as well as Commercial Potting media but not in 100% vermicompost application and inorganic treatment. Relative root growth has been higher in treatments G_{60}, G_{CM60}; G_{80}, G_{CM80}; G_{vw} G_{CMvw}. Highest germination index was achieved with application of 60, 80% vermicompost in soil and 80% vermicompost in commercial potting media in $\mathrm{LV_1}$ and $\mathrm{LV_2}$, respectively. The seedling vigour index

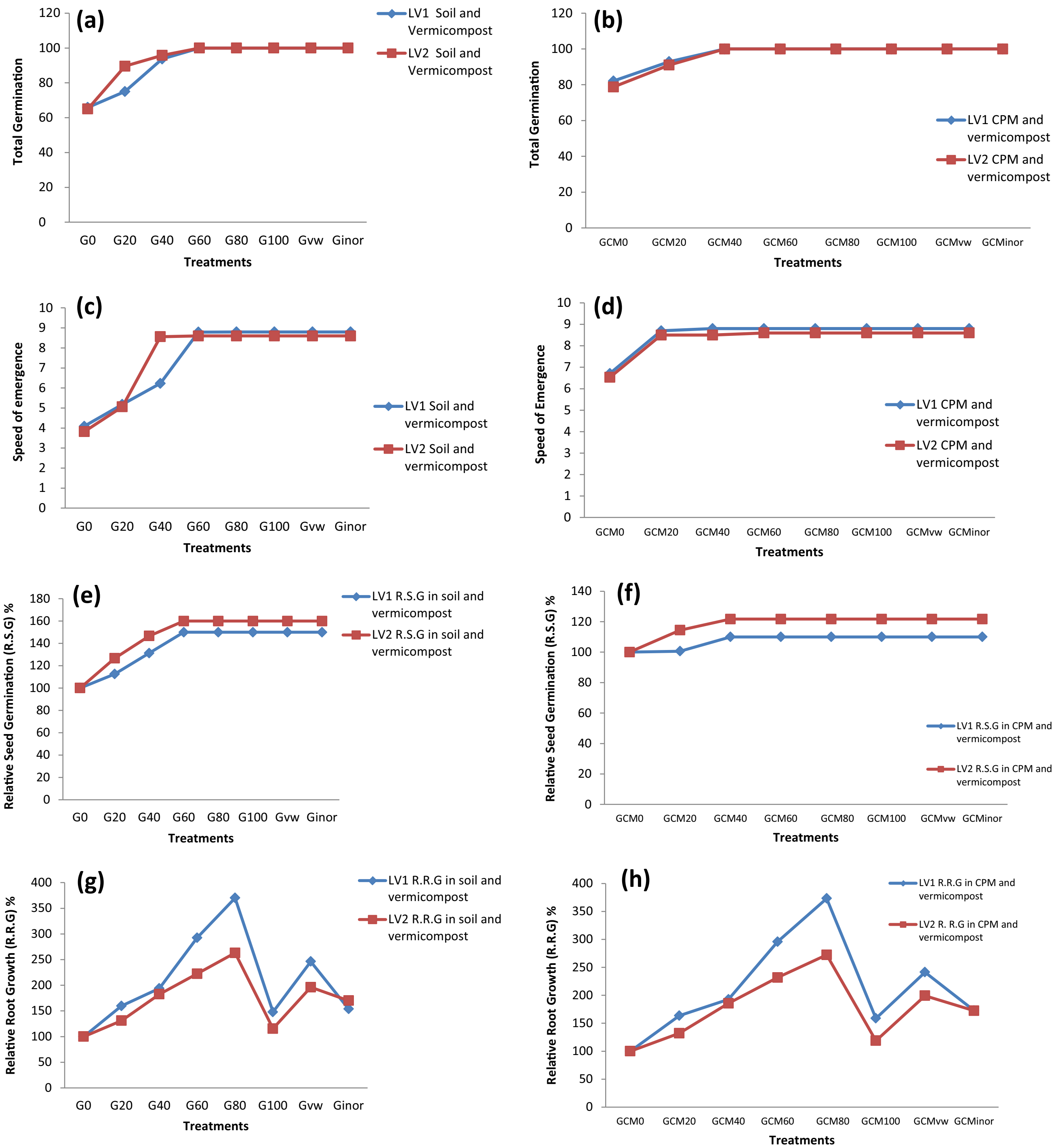

Fig. 1 Analysis of various seedling growth parameters in two varieties Linseed Plants LC- 54 (LV_1) and LC- 2063 (LV_2): **a**, **b** total germination; **c**, **d** speed of emergence; **e**, **f** relative seed germination; **g**, **h** relative root growth under different treatments

(S.V.I) showed significant difference ($p < 0.05$) and was highest with dosage of 60% v/v vermicompost, irrespective of substrate being soil or commercial potting media (Table 5). Substituting soil and commercial potting media with vermicompost show comparable S.V.I and Germination Index (G.I) in treatments G_{20} and G_{CM20}; G_{40} and G_{CM40}; G_{60} and G_{CM60}; G_{vw} and G_{CMvw}. Results indicated that the role of vermiwash and vermicompost as potting media can be no less than commercial potting media.

Scope of vermicompost to be used as an alternative to commercial potting substrates or peat is indicated in present study of germination indices. Vermicompost substitution in commercial potting media and soil showed no negative effect on *Linum* seed germination in all proportions, so vermicompost can be used to replace the expensive commercial potting media partially or whole. Similar results have been put forth by Atiyeh et al. (1999, 2000a, 2001) using pig manure as container media. Replacing vermicompost with commercial potting media would reduce substrate cost in nurseries thus in turn reducing peat harvesting from wetlands. Ievinsh (2011) reported that application of more than 50% vermicompost, inhibited seed germination in radish, cabbage, swedish turnip, beet root, beans and peas. Contrary to this, in present study, germination rate of *Linum* varieties was not negatively affected by increasing the proportion of vermicompost in soil. Even 100% vermicompost did not inhibit the seed germination but seedlings showed lower, relative root growth, S.V.I and biomass at 21 DAS, It can be due to excessive micro and macro nutrients in plant tissues. The concentration of nutrients in plant tissues have been shown to be directly proportional to the concentration of nutrients in medium (Truong and Wang 2015). Atiyeh et al. (2000b) also reported similar results that 100% vermicompost caused tomato seedling to be relatively short, with few leaves and lesser weight.

The morpho-physiological parameters of seedling were compared and analysed in all the treatments at different DAS. Till 21 days after sowing (DAS), shoot length and seedling length increases with increase in vermicompost proportion up to 60% dosage, with highest values of shoot length being (7.23 ± 0.042) mm in LC-54 and (6.48 ± 0.113) mm in LC-2063 (Table 6). Similar pattern has been observed for root length of both varieties. Shoot length in treatment with vermiwash was comparable for LV_1 (6.27 ± 0.156) mm and LV_2 (5.95 ± 0.049) mm. Tall seedlings are believed to be genetically superior (Nienstaedt 1981; Campbell and Sorensen 1984) as height of seedling shows its physiological status. Height and stem diameter of seedling are a measure of field survival and field performance (Mullin and Svaton 1972).

Vegetative growth

Vermicompost application has been proved to be efficient in promoting the root formation, plant height and plant biomass as observed in many horticultural plants (Singh et al. 2008). At 35 DAS root collar diameter was maximum in the plants sprayed with vermiwash (2.15 ± 0.07) in LV_1 and (1.91 ± 0.05) and in LV_2. This indicates the role of foliar spray of vermiwash in promoting root growth. Fresh and dry biomass of the seedling of LV_1 and LV_2 was highest in plants treated with vermiwash, that is, 3.34 ± 0.01 g, 3.27 ± 0.01 g and 0.35 ± 0.05 g, 0.34 ± 0.01 g, respectively, when compared with 60%

Table 5 Seed germination index (G.I) and seedling vigour index (S.V.I) in LV_1 and LV_2 varieties of *Linum* in soil and commercial potting media substituted with vermicompost, vermiwash and inorganic fertilizers

Germination studies using vermicompost in soil					Germination studies using vermicompost in commercial media				
Treatments	Germination index		Seedling vigour index		Treatments	Germination index		Seedling vigour index	
	LV_1	LV_2	LV_1	LV_2		LV_1	LV_2	LV_1	LV_2
G_0	100 ± 0^g	100 ± 0^g	2.16 ± 0.19^e	1.41 ± 0.08^g	G_{CM0}	100 ± 0^f	100 ± 0^g	2.18 ± 0.04^e	1.78 ± 0.04^e
G_{20}	179.6 ± 9.70^f	166.03 ± 2.69^f	3.69 ± 0.43^d	2.13 ± 0.08^f	G_{CM20}	174.12 ± 5.50^e	151.2 ± 16.92^f	3.73 ± 0.08^d	2.32 ± 0.14^d
G_{40}	254.9 ± 3.81^d	267.7 ± 5.69^d	5.45 ± 0.30^{bc}	4.03 ± 0.15^d	G_{CM40}	211.86 ± 3.08^d	225.88 ± 1.83^{cd}	5.58 ± 0.05^b	4.52 ± 0.15^c
G_{60}	438 ± 2.26^b	355.7 ± 3.60^b	7.26 ± 0.75^a	6.56 ± 0.079^a	G_{CM60}	325.27 ± 1.56^b	281.91 ± 2.36^b	7.29 ± 0.17^a	7.02 ± 0.16^a
G_{80}	555.5 ± 5.65^a	420.9 ± 6.87^a	4.8 ± 0.62^{cd}	4.96 ± 0.04^c	G_{CM80}	410.5 ± 1.9^a	331.41 ± 4.21^a	4.32 ± 0.079^{cd}	4.81 ± 0.02^c
G_{100}	221.68 ± 19.85^e	184.83 ± 7.73^e	1.9 ± 0.43^e	1.92 ± 0.23^f	G_{CM100}	220.57 ± 1.55^d	184.45 ± 5.80^e	1.91 ± 0.13^e	1.96 ± 0.08^e
G_{vw}	369.45 ± 3.85^c	313.79 ± 2.10^c	6.38 ± 0.19^{ab}	5.93 ± 0.03^b	G_{CMvw}	265.43 ± 1.49^c	242.54 ± 0.90^c	7.21 ± 0.02^a	6.32 ± 0.072^b
G_{inor}	230.59 ± 7.25^{de}	272 ± 11.55^d	4.1 ± 0.26^d	2.5 ± 0.1^e	G_{CMinor}	189.86 ± 14.86^e	209.78 ± 1.03^d	4.9 ± 0.66^c	2.34 ± 0.05^d

Turkey test at a level of 5% of probability was applied. The averages followed by the same letter in a row do not differ statistically

Table 6 Plant growth parameters studied in two varieties of *Linum* at different time intervals under various treatments

Parameters studied	*Linum* varieties	Treatments subjected to the two varieties of *Linum* plants							
		P_0	P_{20}	P_{40}	P_{60}	P_{80}	P_{100}	P_{vw}	P_{inor}
Above ground characteristics									
At 21 (DAS)									
Shoot length[a]	LV_1	3.11 ± 0.170	4.450 ± 0.212	6.25 ± 0.071	7.23 ± 0.042	4.8 ± 0.000	2.15 ± 0.354	6.27 ± 0.156	2.9 ± 0.141
	LV_2	2.23 ± 0.042	2.6 ± 0.141	4.25 ± 0.212	6.48 ± 0.113	4.68 ± 0.396	2 ± 0.141	5.965 ± 0.049	1.383 ± 0.165
Seedling length	LV_1	5.38 ± 0.396	7.37 ± 0.672	10.41 ± 0.156	13.83 ± 0.099	12.96 ± 0.092	6.39 ± 1.287	11.77 ± 0.106	7.8 ± 1.556
	LV_2	5.69 ± 0.007	7.3 ± 0.141	10.48 ± 0.255	12.94 ± 0.346	13.84 ± 0.205	6.38 ± 0.735	12.73 ± 0.099	7.79 ± 0.993
Fresh shoot weight[b]	LV_1	1.17 ± 0.035	2.01 ± 0.000	2.15 ± 0.049	3.03 ± 0.071	1.51 ± 0.028	1.27 ± 0.021	2.72 ± 0.042	1.59 ± 0.170
	LV_2	1.03 ± 0.247	2.1 ± 0.035	2.09 ± 0.049	1.73 ± 0.339	1.39 ± 0.113	1.12 ± 0.007	2.7 ± 0.170	1.41 ± 0.516
Below ground characteristics									
At 21 (DAS)									
Root length	LV_1	2.365 ± 0.092	3.625 ± 0.106	4.31 ± 0.014	6.5 ± 0.000	8.115 ± 0.163	3.54 ± 0.057	5.535 ± 0.092	3.55 ± 0.212
	LV_2	3.365 ± 0.092	4.5 ± 0.000	6.28 ± 0.028	7.665 ± 0.049	9.015 ± 0.021	3.53 ± 0.608	6.715 ± 0.021	5.915 ± 0.120
Above ground characteristics									
At 35 (DAS)									
Shoot length	LV_1	13.78 ± 0.587	21.50 ± 0.148	35.11 ± 0.445	38.2 ± 0.240	26.75 ± 0.919	28.45 ± 0.071	36.33 ± 0.191	22.71 ± 0.969
	LV_2	14.56 ± 0.092	23.35 ± 0.212	41.08 ± 0.587	35.3 ± 0.849	28.78 ± 0.163	18.25 ± 0.212	37.25 ± 0.071	18.95 ± 0.919
Biomass accumulation	LV_1	0.327 ± 0.036	0.399 ± 0.012	0.408 ± 0.001	0.442 ± 0.004	0.273 ± 0.080	0.344 ± 0.001	0.507 ± 0.001	0.375 ± 0.005
	LV_2	0.356 ± 0.014	0.377 ± 0.037	0.461 ± 0.001	0.440 ± 0.007	0.404 ± 0.023	0.320 ± 0.033	0.449 ± 0.033	0.373 ± 0.006
Dry shoot weight	LV_1	0.175 ± 0.002	0.188 ± 0.001	0.196 ± 0.003	0.221 ± 0.004	0.160 ± 0.003	0.140 ± 0.004	0.235 ± 0.005	0.187 ± 0.006
	LV_2	0.184 ± 0.003	0.214 ± 0.004	0.217 ± 0.003	0.021 ± 0.001	0.190 ± 0.002	0.176 ± 0.005	0.240 ± 0.004	0.197 ± 0.001
Fresh shoot weight	LV_1	1.45 ± 0.450	2.31 ± 0.308	2.61 ± 0.180	3.08 ± 0.274	1.69 ± 0.245	1.85 ± 0.080	2.88 ± 0.046	1.66 ± 0.587
	LV_2	0.963 ± 0.212	2.107 ± 0.287	2.617 ± 0.154	2.060 ± 0.233	1.710 ± 0.170	1.233 ± 0.320	2.883 ± 0.158	1.250 ± 0.066
Root diameter[c]	LV_1	0.67 ± 0.05	0.88 ± 0.05	2.81 ± 0.11	3.06 ± 0.08	1.80 ± 0.03	2.24 ± 0.22	3.23 ± 0.16	2.45 ± 0.21
	LV_2	0.72 ± 0.05	0.87 ± 0.16	1.94 ± 1.68	1.78 ± 1.45	1.39 ± 0.90	1.14 ± 0.55	2.02 ± 1.80	1.79 ± 1.47
Below ground characteristics									
At 35 (DAS)									
Root length	LV_1	4.19 ± 0.127	5.22 ± 0.035	6.43 ± 0.092	7.94 ± 0.064	8.16 ± 0.226	4.71 ± 0.021	6.52 ± 0.537	5.76 ± 0.057
	LV_2	4.64 ± 0.057	5.74 ± 0.205	8.76 ± 0.049	7.91 ± 0.014	10.66 ± 0.233	5.64 ± 0.064	8.15 ± 0.078	5.89 ± 0.233
Root collar diameter	LV_1	1.15 ± 0.354	1.335 ± 0.049	1.475 ± 0.035	1.555 ± 0.205	0.97 ± 0.085	1.335 ± 0.771	2.15 ± 0.071	1.435 ± 0.092
	LV_2	0.855 ± 0.064	1.205 ± 0.007	1.34 ± 0.085	1.315 ± 0.021	0.795 ± 0.177	0.875 ± 0.078	1.91 ± 0.057	1.04 ± 0.042
Fresh Root weight	LV_1	0.063 ± 0	0.123 ± 0.01	0.45 ± 0.03	0.42 ± 0.01	0.673 ± 0.01	0.676 ± 0.07	0.446 ± 0.01	0.566 ± 0.13
	LV_2	0.070 ± 0.026	0.127 ± 0.021	0.407 ± 0.025	0.450 ± 0.036	0.657 ± 0.065	0.667 ± 0.057	0.383 ± 0.006	0.550 ± 0.135
Dry root weight	LV_1	0.057 ± 0.006	0.075 ± 0.003	0.097 ± 0.001	0.08 ± 0.001	0.043 ± 0.012	0.048 ± 0.001	0.119 ± 0.003	0.07 ± 0.001
	LV_2	0.065 ± 0.004	0.080 ± 0.009	0.01 ± 0.001	0.092 ± 0.002	0.037 ± 0.004	0.056 ± 0.004	0.107 ± 0.006	0.073 ± 0.001

Table 6 continued

Parameters studied	*Linum* varieties	Treatments subjected to the two varieties of *Linum* plants							
		P_0	P_{20}	P_{40}	P_{60}	P_{80}	P_{100}	P_{vw}	P_{inor}
Above ground characteristics									
At 50 DAS									
Stem basal area	LV_1	2.365 ± 0.092	3.625 ± 0.106	4.31 ± 0.014	8.115 ± 0.163	6.5 ± 0.000	3.54 ± 0.057	5.535 ± 0.092	3.55 ± 0.212
	LV_2	3.365 ± 0.092	4.5 ± 0.000	9.015 ± 0.021	7.665 ± 0.049	6.28 ± 0.028	3.53 ± 0.608	6.715 ± 0.021	5.915 ± 0.120
Leaf weight	LV_1	45.95 ± 0.495	46.95 ± 0.212	47.25 ± 0.071	48.4 ± 0.424	44.55 ± 1.485	46.25 ± 0.636	53 ± 0.990	47.5 ± 0.424
	LV_2	47.3 ± 0.141	49.1 ± 0.283	52.59 ± 0.70	50.1 ± 0.990	47.2 ± 0.424	47.35 ± 0.778	54.4 ± 0.141	48.95 ± 0.919
Complete plant characteristics									
At harvest									
Shoot length	LV_1	114.65 ± 9.758	130.7 ± 3.111	135.15 ± 0.707	136.4 ± 0.566	125 ± 1.131	126.1 ± 7.354	135.95 ± 0.990	130.75 ± 1.273
	LV_2	122.2 ± 2.546	134.2 ± 7.637	139.4 ± 1.414	138.8 ± 0.283	125.7 ± 5.940	126.25 ± 1.556	138.4 ± 0.566	132.45 ± 2.687
Root length	LV_1	11.2 ± 0.566	14.93 ± 0.587	17.78 ± 0.191	19.08 ± 0.205	10.62 ± 0.863	9.9 ± 0.566	18.17 ± 0.233	15.83 ± 0.643
	LV_2	12.38 ± 1.089	14.93 ± 0.587	17.96 ± 0.078	17.63 ± 0.134	10.35 ± 0.813	11.32 ± 0.042	18.27 ± 0.488	16.8 ± 0.311
Root weight	LV_1	1.175 ± 0.078	1.775 ± 0.064	1.895 ± 0.049	2.255 ± 0.078	1.145 ± 0.092	1.53 ± 0.622	2.99 ± 0.113	1.805 ± 0.021
	LV_2	1.555 ± 0.177	1.885 ± 0.049	2.115 ± 0.134	1.925 ± 0.064	1.71 ± 0.113	1.165 ± 0.205	2.95 ± 0.028	1.925 ± 0.049
Shoot weight	LV_1	14.8 ± 0.170	15.985 ± 0.431	16.825 ± 0.134	17.425 ± 0.148	14.205 ± 0.884	13.865 ± 0.205	19.01 ± 0.057	15.94 ± 0.537
	LV_2	15.5 ± 0.255	17.755 ± 0.219	19.11 ± 0.297	17.96 ± 0.042	14.35 ± 0.806	13.875 ± 0.361	20.025 ± 0.290	16.98 ± 0.354
Plant biomass	LV_1	14.21 ± 1.584	16.995 ± 0.021	18.035 ± 0.134	18.385 ± 0.474	14.38 ± 0.849	13.925 ± 0.573	19.82 ± 0.269	18.275 ± 0.502
	LV_2	16.06 ± 0.212	17.655 ± 0.445	19.54 ± 0.410	18.96 ± 0.099	16.995 ± 0.021	15.685 ± 0.898	20.455 ± 0.559	18.185 ± 0.219
Biomass accumulation	LV_1	0.054 ± 0.040	0.076 ± 0.051	0.079 ± 0.051	0.091 ± 0.057	0.054 ± 0.036	0.063 ± 0.024	0.115 ± 0.067	0.079 ± 0.051
	LV_2	0.070 ± 0.052	0.074 ± 0.041	0.081 ± 0.048	0.075 ± 0.041	0.084 ± 0.065	0.058 ± 0.049	0.107 ± 0.056	0.078 ± 0.045

[a] Length in cm; [b] weight in g and [c] diameter in mm

vermicompost in both the varieties that is 2.9 ± 0.27 g, 2.8 ± 0.15 g in LV_1 and 0.328 ± 0.01 g, 0.113 ± 0.01 g in LV_2.

Plants treated with chemical fertilizer showed thinner stems and less deep root system as compared to vermicompost. Beyond 60% dosage of vermicompost showed no further increase in shoot length, root length, shoot weight, root weight and stem diameter at 50 DAS (Table 6). With the application of greater proportions of vermicompost, the plant growth parameters have not improved, this is in accordance with studies done by Subler et al. (1998) so higher doses of vermicompost had detrimental effects on Linseed plants after 35 days of sowing, which may be attributed to higher ammonium content disrupting the mechanism of nutrient absorption through plant roots (Atiyeh et al. 2000a).

At harvest, plants treated with foliar spray of vermiwash had shorter shoot length with high stem basal area than the plants treated with 60% vermicompost in LV_1 and 40% vermicompost in LV_2. Vermiwash-treated plants had extensive root system with greater root volume and root length, whereas plants treated with chemical fertilisers had weak, thin and poorly branched root system. These results are in corroboration with the studies done by Lazcano et al. (2009). Enhanced root growth parameters can be attributed to the presence of humic acid in vermicompost and vermiwash. Humic acids have been known to enhance root growth (Tallini et al. 1991) and nutrient uptake by increasing the root cell membrane permeability (Valdrighi et al. 1996).

At low to moderate concentrations of vermicompost increased vegetative and reproductive growth is due to appropriate modification of physico-chemical and microbiological status of growing medium. This is in accordance with the studies of Truong and Wang (2015) on tomato seedlings. Optimized dosage of vermicompost was 20% in French marigold seedlings (Bachman and Metzger 2008), up to 60% of cattle manure vermicompost in Petunia (Arancon et al. 2008), 40% of vermicompost in green house peppers(Arancon et al. 2004) and below 50% in tomato (Atiyeh et al. 2000b; Hashemimajd et al. 2006). Though some studies have also shown the best plant performance from 50 to 100% (Lazcano et al. 2009).

There was no significant difference ($p > 0.05$) between biomass allocation and branching ratio in soil and commercial media. Higher branching ratio at 35 days showed the potential of the plantling for higher fruiting and seed setting. Branching in both the varieties is up to third order, i.e. primary, secondary and tertiary being up to 35, 20 and 5 cm long, respectively. There was great variation in branching pattern and number in all treatments (Table 7). The treatment with vermicompost and vermiwash (P_{vw}) showed bushier appearance of plants with branching up to fifth order. Profuse branching is directly correlated to the crop yield in Linseed. Plants treated with 40–60% vermicompost and with vermiwash treatment had started early and uniform branching in all the plants, by vermicompost substitution both in soil or commercial potting media, which clearly signifies the role of vermicompost in promoting vegetative growth. Interestingly, at harvest the highest fruits were also obtained in same treatments, i.e. with 40–60% dosage of vermicompost and vermiwash application.

In both the varieties, plants provided with vermicompost gave better results than that supplemented with the inorganic fertilisers. All the replicates treated with vermicompost and vermiwash had relatively uniform growth pattern than the plants treated with inorganic fertilisers. Although, the nutrients are sufficiently provided in the inorganic treatment but better growth with vermicompost may be attributed to presence of unique mesophylic bacteria, fungi and worm secretions in vermicompost. This signifies that vermicompost is not all about nutritional enrichment but involvement of richer microbial, enzymatic activity of soil and plant growth regulators (Subler et al. 1998; Zaller 2006).

Vermicompost seems to promote nutrient absorption, so the plant with higher doses of vermicompost show relatively poor growth likely due to excessive nutrient absorption and toxicity; reduced aeration and porosity of medium; absorption of heavy metal and excessive phytotoxic substances; and excessive humic acid (Sani 2014). Combination of vermicompost and foliar spray of vermiwash presented better growth till flowering and fruiting stage due to frequent supplementation and foliar absorption of the vermiwash (Khan et al. 2014).Vermiwash has also been proven to replenish the deficiency of potassium and phosphorus in Tomato seedlings (Arthur et al. 2012). Plants treated with foliar spray of vermiwash and vermicompost were consistently been observed to have shorter height and sturdier basal area than the plants treated with 40 or 60% vermicompost till the completion of the study in both the varieties. Sturdier plants proved to be an added advantage to the crop till maturity. Till harvest, shoot length, root length, root weight, shoot weight, plant biomass and biomass accumulation was appreciably high in P_{vw} in both the varieties, in the studies conducted in both years.

Flowering, fruiting and yields

Two varieties respond significantly ($p < 0.05$) during flowering and seedfill stage. Results explain that foliar application of vermiwash has shortened the lifecycle of Linseed plant, thus favouring farmers (Table 8). Vermiwash also caused early ripening of capsules and early browning of stems and leaves. Leaf stages, flowering, fruit

Table 7 Comparison of seedling performance in terms of biomass allocation and branching ratios in two varieties of *Linum* LV_1 and LV_2 in different treatments

Germination studies using vermicompost in soil					Germination studies using vermicompost in commercial media				
Treatments	Biomass allocation		Branching ratio		Treatments	Biomass allocation		Branching ratio	
	LV_1	LV_2	LV_1	LV_2		LV_1	LV_2	LV_1	LV_2
G_0	0.043 ± 0.0[e]	0.072 ± 0.005[g]	4:01	03:01	G_{CM0}	0.038 ± 0.007[e]	0.064 ± 0.005[de]	1.5:1	1.71:1
G_{20}	0.053 ± 0.004[e]	0.057 ± 0.004[g]	1.71:1	1.71:1	G_{CM20}	0.047 ± 0.003[e]	0.048 ± 0.002[e]	1.09:1	1.51:1
G_{40}	0.172 ± 0.006[c]	0.197 ± 0.001[d]	01:01	01:01	G_{CM40}	0.159 ± 0.010[c]	0.179 ± 0.002[c]	01:01	01:01
G_{60}	0.136 ± 0.001[d]	0.172 ± 0.001[e]	1.09:1	01:01	G_{CM60}	0.162 ± 0.002[c]	0.166 ± 0.002[c]	01:01	01:01
G_{80}	0.39 ± 0.026[a]	0.383 ± 0.002[b]	1.71:1	02:01	G_{CM80}	0.236 ± 0.005[b]	0.363 ± 0.002[b]	1.33:1	1.71:1
G_{100}	0.295 ± 0.003[b]	0.31 ± 0.018[c]	2.4:1	02:01	G_{CM100}	0.297 ± 0.001[a]	0.301 ± 0.003[b]	2.4:1	02:01
G_{vw}	0.154 ± 0.081[cd]	0.132 ± 0.103[f]	01:01	1.71:1	G_{CMvw}	0.165 ± 0.075[c]	0.147 ± 0.089[cd]	01:01	04:01
G_{inor}	0.039 ± 0.003[e]	0.44 ± 0.007[a]	02:01	01:01	G_{CMinor}	0.073 ± 0.007[d]	0.69 ± 0.081[a]	03:01	01:01

Tukey's test at a level of 5% of probability was applied. The averages followed by the same letter in a column are not differ statistically

maturity was earlier achieved in P_{vw} (15, 106.5 and 130 days) than in control P_0 (18.5, 128, 148 days) in LV_1, whereas in LV_2 earliest stages were achieved in P_{vw} (13.5, 114.5 and 135 days) than in control (17, 121.5 and 144 days). Foliar application of vermiwash during seedfill and seed maturity stage seemed to be non-significant but fruit yield was higher in P_{vw} may be due to the previous applications of vermiwash. Variety of LV_1 had delayed flowering and fruiting than LV_2 which can be attributed to genotypic differences in two varieties. The varied effects of vermicompost among different varieties of same genus indicate the role of genotype in specific response to any organic amendment (Zaller 2007; Lazcano et al. 2010) as some varieties may be more sensitive and better responding at specific dosage.

Plants treated with the combination of 50% vermicompost and a foliar spray of vermiwash (P_{vw}) turned out to be the highest yielding plants with more branches, higher number of capsules, highest plant dry weight and maximum number of seeds (Table 9). Positive effects of vermiwash in this study coincide with results from Gutierrez-miceli et al. (2008) and Tejada et al. (2008).Vermiwash is believed to contain plant growth hormones, enzymes and vitamins from earthworm-associated microbes (Suthar 2010).Vermiwash promotes plant growth by physical amelioration of substrate and influencing nutrient uptake mechanism (Alvarez and Grigera 2005).

The percentage of capsule number in P_{vw} is 49.35, 45.51% higher than P_{inor} and 138.72, 95.5% higher than P_0 in LV_1 and LV_2, respectively (Table 9). During plant growth, initially the root growth is fast but later on, flower, fruit and seed become the sink of plant resources. Leaf weight was consistently high in P_{vw} indicating high photosynthetic efficiency with foliar application of vermiwash. Thus, greater fruit and seed number in P_{VW} is resultant of increased photosynthetic efficiency of the plant with vermiwash treatments. Total capsule number in P_{vw} was 4.04% higher than in P_{40} in LV_1 and 3.8% higher in LV_2 than P_{60}, in both the trials. Maximum fruit yield in numbers was obtained in P_{vw} in first harvest after 128 DAS. In second harvest, fruit yield was very low in treatment with vermiwash in both the varieties. The highest yield of fruit (%) in first harvest of both varieties in P_{vw} (93.97 ± 1.93, 95.27 ± 0.84) shows even and uniform ripening of the fruit when fruit yield in first and second harvest was compared. It suggests the uniform maturation and fruit ripening is achieved with foliar spray of vermiwash.

Average seed number per capsule was highest being 7.58 in first trial and 7.3 in second trial in LV_1 and was 7.25 and 7.05 in LV_2 in treatment with vermiwash. With inorganic treatment, seed number per capsule in P_{inor} was 5.66, 5.5 and 5.88, 5.95 in two trials of both varieties, respectively. Maximum seed yield (in g/plant) was obtained in P_{vw} in LV_1 and LV_2 followed by P_{40} in LV_1 and P_{60} in LV_2. High capsule number and seed yield in treatments P_{vw} can be attributed to extensive and profusely branched root system. Harvest index in LV_1 in P_{vw} is (66.75 ± 0.661) and in LV_2 is (57.56 ± 0.751), which is comparable to P_{40} in LV_1 and P_{60} in LV_2 and is 60.3, 34.97% higher than P_{inor} in both varieties. Even the application of low doses, i.e. 20% vermicompost has significantly enhanced the capsule number per plant (82.4% more in LV_1, 64.1% in LV_2), Fruit ripening (212% in LV_1, 185.5% in LV_2), yield in first harvest (26.8% in LV_1, 34.2% in LV_2), seed yield (56.2% in LV_1, 39.1% in LV_2) and H.I (29.7% in LV_1, 26.6% in LV_2) when compared with control P_0.

Furthermore, the foliar applications of vermiwash reduced the incidence of capsule malformation. This relatively healthier, higher yield and a lesser malformed fruit

Table 8 Effect of vermicompost on the duration of major stages in life cycle of *Linum* plants under different treatments

Treatments	Stage-1 Average number of days to seedling emergence		Stage-2 Average number of days to leaf stages		Stage-3 Average number of days to flowering		Stage-4 Average number of days to seedfill and seed maturity	
	LV_1	LV_2	LV_1	LV_2	LV_1	LV_2	LV_1	LV_2
P_0	14.5 ± 0.50^{a}	16.0 ± 1.14^{a}	18.5 ± 0.43^{a}	17.0 ± 0.50^{a}	128 ± 0.86^{a}	121.5 ± 0.43^{bc}	148 ± 1.32^{a}	144 ± 0.90^{bc}
P_{20}	10.0 ± 0.00^{b}	11.5 ± 0.43^{b}	14.5 ± 0.4^{d}	13.5 ± 0.43^{cd}	109.5 ± 0.66^{cd}	114 ± 0.86^{c}	133 ± 1.8^{bcd}	141.5 ± 3.04^{c}
P_{40}	10.0 ± 0.00^{b}	10.5 ± 0.43^{bc}	16.5 ± 0.50^{bc}	13.0 ± 0.50^{d}	106 ± 0.90^{e}	122.5 ± 1.80^{abc}	129.5 ± 1.29^{d}	142.5 ± 3.01^{c}
P_{60}	9.50 ± 0.50^{b}	10.5 ± 0.43^{bc}	16.5 ± 0.50^{bc}	14.5 ± 0.43^{bcd}	110.5 ± 1.00^{c}	121.5 ± 1.32^{bc}	136 ± 3.96^{bc}	144.5 ± 1.73^{bc}
P_{80}	9.50 ± 0.50^{b}	10.0 ± 0.00^{c}	16.5 ± 0.50^{bc}	15.0 ± 0.89^{bc}	115 ± 1.80^{b}	128 ± 7.79^{ab}	145 ± 3.46^{a}	148.5 ± 0.43^{ab}
P_{100}	9.50 ± 0.50^{b}	10.0 ± 0.00^{c}	17.6 ± 5.7^{ab}	15.5 ± 0.43^{ab}	118 ± 0.86^{b}	131 ± 2.61^{a}	149.5 ± 0.43^{a}	151.5 ± 0.43^{a}
P_{vw}	9.5 ± 0.50^{b}	10.0 ± 0.0^{c}	15.0 ± 0.0^{cd}	13.5 ± 0.44^{cd}	106.5 ± 1.31^{de}	114.5 ± 0.50^{c}	130 ± 1.32^{cd}	135 ± 1.00^{d}
P_{inor}	9.5 ± 0.50^{b}	10.0 ± 0.00^{c}	16.0 ± 0.9^{cd}	15.5 ± 0.44^{ab}	109.5 ± 0.66^{cd}	127.5 ± 0.50^{ab}	137.5 ± 2.16^{b}	148.5 ± 2.17^{ab}

Values are the average number of days after seed sowing (DAS). Tukey's test at a level of 5% of probability was applied. The averages followed by the same letter in a column do not differ statistically

Stage-1: When cotyledons first seen unfolded in 50% of plants

Stage-2: When four leaves unfolded in all seedlings

Stage-3: When at least single flower was observed on all the plant

Stage-4: When at least 10% of seeds have reached final size

Table 9 Effect of various treatments on yield and harvest indices of the two varieties of *Linum*

Parameters studied	Varieties under treatment	Yield and harvest indices of two varieties of *Linum* under different treatments							
		P_0	P_{20}	P_{40}	P_{60}	P_{80}	P_{100}	P_{vw}	P_{inor}
Capsule number per plant	LV_1	97.66 ± 10.37	178.16 ± 5.42	221 ± 11.31	179.83 ± 4.48	153 ± 5.65	167.66 ± 9.42	233 ± 16.97	156 ± 7.07
	LV_2	123.16 ± 5.89	202.16 ± 12.4	204.16 ± 4.47	218.5 ± 6.36	122.16 ± 6.83	143.16 ± 5.89	240.83 ± 11.5	165.5 ± 9.1
Capsule weight/100 capsules (gm)	LV_1	3.865 ± 0.72	3.77 ± 0.14	4.795 ± 0.24	5.86 ± 0.07	3.845 ± 0.10	2.71 ± 0.49	5.55 ± 0.22	3.505 ± 0.44
	LV_2	3.525 ± 0.24	3.84 ± 0.04	4.47 ± 0.21	5.765 ± 0.20	3.87 ± 0.07	3.135 ± 0.10	5.45 ± 0.08	3.81 ± 0.41
Number of seeds per capsule	LV_1	5.36 ± 0.06	5.91 ± 0.82	7.05 ± 0.50	7.22 ± 0.03	6.34 ± 0.33	6.445 ± 0.30	7.44 ± 0.19	5.77 ± 0.15
	LV_2	5.04 ± 0.05	5.81 ± 0.37	6.5 ± 0.00	6.96 ± 0.16	6.66 ± 0.23	6.56 ± 0.26	7.15 ± 0.14	5.725 ± 0.31
Ratio of ripe to unripe fruit	LV_1	1.415 ± 0.17	4.415 ± 0.51	8.345 ± 0.6	6.41 ± 1.28	3.495 ± 0.45	4.1 ± 0.50	11.23 ± 0.6	2.755 ± 0.02
	LV_2	1.73 ± 0.14	4.92 ± 0.89	11.18 ± 1.8	7.955 ± 0.38	3.77 ± 0.84	3.46 ± 0.72	13.02 ± 1.1	3.375 ± 0.19
Yield in 1st harvest (%)	LV_1	65.86 ± 6.99	83.53 ± 2.54	91.09 ± 2.29	88.59 ± 2.20	81.82 ± 3.03	84.98 ± 4.78	93.97 ± 1.93	84.78 ± 3.84
	LV_2	66.24 ± 0.87	88.91 ± 2.43	93.21 ± 2.27	92.00 ± 0.21	82.98 ± 3.19	82.41 ± 2.25	95.27 ± 0.84	81.14 ± 0.56
Seed yield per plant (gm)	LV_1	5.76 ± 0.06	9.00 ± 1.08	12.14 ± 0.76	10.19 ± 0.04	8.37 ± 0.39	8.96 ± 0.37	13.23 ± 0.31	7.60 ± 0.17
	LV_2	6.29 ± 0.45	8.75 ± 0.26	9.36 ± 0.43	10.81 ± 0.05	6.43 ± 0.10	7.48 ± 0.37	11.78 ± 0.48	7.76 ± 0.88
Harvest index	LV_1	40.80 ± 4.95	52.94 ± 6.26	67.28 ± 3.69	55.41 ± 1.19	58.25 ± 0.74	64.35 ± 0.01	66.75 ± 0.66	41.61 ± 2.09
	LV_2	39.14 ± 2.26	49.57 ± 2.73	47.92 ± 3.21	57.03 ± 0.58	37.83 ± 0.60	47.83 ± 5.08	57.56 ± 0.75	42.64 ± 4.32

incidence can be attributed to the presence of certain micro-nutrient as calcium, magnesium, manganese, copper, boron, iron, amino acids and silicic acid in vermiwash (Jarecki et al. 2005).Yield of the Linseed oil from the crop is positively co-related to the seed number and the seed weight per capsule per plant. Thus, high seed and capsule number will increase gains from Linseed. Organically grown Linseed in no way has negative effect on farming economics, as the positive increase in marketable yield is there in organic Linseed production.

In Linseed, the dry weight of stem at harvest is of great importance as linen fibre is commercially obtained from its retted stems. Plant biomass at harvest is highest in P_{vw} (19.82 ± 0.269)g in LV_1 and (20.455 ± 0.559)g in LV_2. High plant biomass (g) is obtained in P_{20} (16.99 ± 0.021) in LV_1 and (17.65 ± 0.445) in LV_2, P_{40} (18.03 ± 0.134) in LV_1 and (19.54 ± 0.410) in LV_2. P_{60} (18.38 ± 0.474) in LV_1,(18.96 ± 0.09) in LV_2 is comparable with that of P_{inor}. Biomass allocation reflects the shift of plant resources which may be due to availability of nutrients in the micro environment. In the present study, in treatment P_{vw}, Biomass accumulation has shifted more to root from 35 DAS (0.507 ± 0.001; 0.449 ± 0.033) to harvest (0.115 ± 0.067; 0.107 ± 0.056) in LV_1 and LV_2 which is likely to cause better nutrient absorption and hence higher harvest indices.

Vermicompost and vermiwash application may have provided certain resistance to plants by indirectly affecting the pathogens (Edwards et al. 2004) or due to bacteria and fungi in vermicompost (Szczech 1999). No fungicide or pesticide was used in the present study rather no need was felt at any point of trial as there was no incidence of disease manifestation in the crop probably due to the pesticidal and nematicidal properties of vermicompost (Edwards et al. 2004, 2006).

Conclusion

The present study indicates that vermicompost is an environmentally friendly substitute in organic agriculture and have shown beneficial effects with 40–60% as optimum proportion in LC-54 and in LC-2063 varieties of *Linum*. Application of vermicompost has positively enhanced growth of both vegetative and reproductive phase of the plant. The yield of Linseed in current pilot study under organic agriculture was more than inorganic treatment, reflecting the scope of organic production of Linseed. Foliar application of the 50% vermicompost and vermiwash had synergistic effect in *Linum* plant. Vermiwash application has shortened the life cycle of *Linum* and improved the growth parameters like stem diameter, root volume, branching ratio, biomass allocation, fruit weight, average seed number per capsule by improving the physico-chemical, biological and microbial properties of the growing medium; by improving the nutrient absorption through roots and foliar absorption of vermiwash. Yield and performance of LC -54 was better than LC-2063 under vermicompost regime. The consistently different response of two varieties of *Linum* at different doses in both the trials showed that LV_1 is more responsive even at relatively lower doses. Thus, improved plant growth parameters and higher yield obtained with vermicompost alone and integrated with foliar application of vermiwash opens new vistas for organic Linseed production.

Acknowledgements We are thankful to Department of Applied Sciences, Punjab Technical University, Kapurthala, Punjab (India) and Department of Zoology, Khalsa College, Amritsar (India) for providing necessary lab facilities.

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