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Full Length Research Paper

Influence of summer tillage on soil characteristics, weeds diversity and crop yield of certain vegetable crops grown in Tarai region of Ganga River, India

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The influence of summer tillage with moldboard plow, rotary hoe and moldboard plow followed by rotary hoe on the soil characteristics, weeds diversity and crop yield of certain vegetable crops namely: potato (*Solanum tuberosum* L.), carrot (*Daucus carota* subspecies *sativus* L.) and radish (*Raphanus sativus* L.) grown in the northern great plain of River Ganga in India were investigated. The results showed that summer tillage using moldboard plow, rotary hoe and moldboard plow followed by rotary hoe significantly ($P<0.05$/$P<0.01$) affected the soil moisture content, bulk density (BD), water holding capacity (WHC), hydraulic conductivity and microbial biomass of the soil used for the cultivation of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus*. A total of 65 species of weeds were recorded before summer tillage. Summer tillage using moldboard plow significantly ($P<0.05$) reduced the number of weeds species compared to the summer tillage using rotary hoe. Additionally, summer tillage with moldboard plow followed by rotary hoe was observed to be more significant ($P<0.01$) in decreasing the weeds population and weeds diversity. Moreover, plant height, dry weight, chlorophyll content, leaf area index (LAI) and crop yield of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus* were also recorded to be significantly ($P<0.05$) different with summer tillage using moldboard plow followed by rotary hoe in comparison to moldboard plow and rotary hoe when applied separately. Therefore, summer tillage with moldboard plow and followed by rotary hoe must be applied to decrease the weeds population and enhance the agronomical attributes of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus*.

Key words: Conventional tillage, crop yield, mouldboard plough, rotary hoe, summer tillage, weeds diversity.

INTRODUCTION

Tillage is the agricultural preparation of soil by mechanical agitation of various types, such as digging, stirring, and overturning (Yaduvanshi and Sharma, 2008; Kumar and Chopra, 2013). Tillage is often classified into two types namely: primary and secondary. There is no strict boundary between them, though there is a loose distinction between tillage that is deeper and more thorough (primary) and tillage that is shallower and sometimes more selective of location (secondary). The primary tillage such as ploughing tends to produce a rough surface finish, whereas secondary tillage tends to produce a smoother surface finish, such as that required to make a good seedbed for many crops (Peltzer et al., 2009; De Sanctis et al., 2012; Alliaume et al., 2014).

Modern agriculture has greatly reduced the use of tillage. Crops can be grown for several years without any tillage through the use of herbicides to control weeds, crop varieties that tolerate packed soil and equipment that can plant seeds or fumigate the soil without really digging it up (Castillo et al., 2006; Luna et al., 2012). Plough is used in farming for initial cultivation of soil in preparation for sowing seeds or planting to loosen or turn the soil. Ploughs are traditionally drawn by working animals such as horses or cattle, but in modern times are drawn

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by tractors (Andrade et al., 2003; Alliaume et al., 2013). A plough is made of wood, iron, or steel frame with an attached blade or stick used to cut the earth. The primary purpose of ploughing is to turn over the upper layer of the soil, bringing fresh nutrients to the surface, while burying weeds and the remains of previous crops and allowing them to break down. As the plough is drawn through the soil, it creates long trenches of fertile soil called furrows (Ashford and Reeves, 2003; Roldán et al., 2007; Mirás-Avalos et al., 2011). In modern use, a ploughed field is typically left to dry out, and is then harrowed before planting. Plowing and cultivating a soil homogenizes and modifies the upper 12 to 25 cm of the soil to form a plow layer. In many soils, the majority of fine plant feeder roots can be found in the top soil or plow layer (Roldán et al., 2007; Shams and Rafiee, 2007; Kabir et al., 2013). Natural farming methods are emerging that do not involve any ploughing at all, unless an initial ploughing is necessary to break up hardpan on a new plot to be cultivated, so that the newly introduced soil life can penetrate and develop more quickly and deeply (Sharma et al., 2004; Campiglia et al., 2010). On the contrary, without ploughing, beneficial microflora can develop that will eventually bring air into the soil, retain water and build up nutrients (Haj and Hemmat, 2000; Jackson et al., 2004; Kumar and Chopra, 2010, 2011; Giovannetti et al., 2012). A healthy soil full of active fungi and microbial life, combined with a diverse crop (making use of companion planting), suppresses weeds, pests naturally and increase water holding capacity (Oehl et al., 2004; Giovannetti et al., 2012). Thus, the intensive use of water, oil and energy hungry irrigation, fertilizers and herbicides are avoided. The cultivated land becomes more fertile and productive over time, while tilled land tends to go down in productivity over time due to erosion and the removal of nutrients with every harvest (Kumar and Chopra, 2010). To grow crops regularly in less fertile areas, the soil must be turned to bring nutrients to the surface (Sharma et al., 2004; Strudley et al., 2008; Kumar and Chopra, 2013). A major advance for this type of farming was the turn plough, also known as the mouldboard plough (UK), moldboard plow (US), or frame-plough (Roger-Estrade et al., 2004; Sharratt et al., 2006; Peltzer et al., 2009). The economic losses due to weeds are encountered nearly everywhere in agriculture. The yields frequently are reduced by weeds competing with vegetables and other crops for water, nutrients and light. The crop choice may be limited by the presence of high populations of weeds (Jabro et al., 2009; Peltzer et al., 2009; Alliaume et al., 2014). Most vegetable crops will not compete effectively against heavy weed growth. The harvesting costs are commonly increased. The mechanical harvesting may be impossible. Root and crop damage may result from cultivation designed to control weeds. The soil structure may be destroyed by repeated cultivation, especially if the soil is wet (Lampurlanes and Cantero-Martinez, 2003; McVay et al., 2006; Luciano et al., 2013). Moreover, weeds may harbor insect and disease organisms that attack vegetables and other crops. All types of vegetables and other crop products may be reduced in quality, rendering them less marketable (Wuest et al., 2005; Luciano et al., 2013). The weeds grow faster than native plants and successfully compete for available nutrients, water, space and sunlight, resulting in reduced crop yield and poor crop quality. Besides this, weeds also pose a problem by reducing the efficiency of water delivery and drainage systems (Kay and Vanden, 2002; Biederbeck et al., 2005; De Sanctis et al., 2012).

Plants require vital nutrients for growth, including nitrogen (N), phosphorus (P) and potassium (K), as well as trace minerals including boron, chlorine, cobalt, copper, iron, manganese, magnesium, molybdenum, sulfur and zinc (Elcio et al., 2003; Gilsanz et al., 2004; Kumar and Chopra, 2011; De Sanctis et al., 2012). Tillage improves soil fertility by acting as nutrient scavengers taking up vital nutrients both above and below the soil compaction zone. Available nitrogen (N), phosphorus (P), calcium (Ca) and sulphur (S) are mineralized during peak tillage (Jansa et al., 2003; Kabir, 2005; Sainju et al., 2007; Mirás-Avalos et al., 2011). The nutrients are then released back into the soil and made available for healthy crop plant growth. Tillage affects decomposition of plant residues in a number of ways. First, tillage increases soil contact with residues and increases the microbes' access to them (Mirás-Avalos et al., 2011; De Sanctis et al., 2012; Kabir et al., 2013). The plow layer is a hospitable environment for microbes, as they are sheltered from extremes of temperature and moisture. Secondly, tillage breaks the residue into smaller pieces, providing more edges for microbes to munch. Thirdly, tillage will temporarily decrease the density of the soil, generally allowing it to drain and therefore warm up more quickly (Peltzer et al., 2009; Campiglia et al., 2010; Luciano et al., 2013). Therefore tillage benefits the soil and resulted in decomposing the residues incorporated into the soil and release nutrients much faster than those left on the surface, as in a no-till system (Yaduvanshi and Sharma, 2008; Campiglia et al., 2010; Mirás-Avalos et al., 2011; Luna et al., 2012; Kabir et al., 2013; Kumar and Chopra, 2013; Alliaume et al., 2014). However, the present investigation was carried out to study the influence of summer tillage on soil characteristics, weeds diversity and crop yield of certain vegetable crops grown in Tarai region of Ganga River, India.

MATERIALS AND METHODS

Description of experimental site

The Agriculture Farm of Gurukula Kangri University at Haridwar, Uttarakhand (29°36'15.81''N 77°14'51''E) in the Tarai region of Ganga River was selected for the present investigation. The Tarai region of Ganga River is stretched over Uttarakhand, Uttar Pradesh, Bihar and West Bengal States of India. The Tarai region of Ganga River is rich in fertile loamy soil suitable for the cultivation of various grains, vegetables, pulses and fruits crops also. The site is characterized by wide variation in mean monthly temperature from 10.5°C in December and

January to 40.7°C in May and June. The average annual precipitation at the research site was from 25 to 40 mm from July to September. The ground water is used for irrigation besides rainfall in the region.

Description of summer tillage practices

The summer tillage is prevalent before sowing of crops in the region, which is effective for the removal of weeds and crop residues due to short gap between two crops. During the present investigation summer tillage was performed with moldboard plow and rotary hoe separately and moldboard plow followed by rotary hoe. The agricultural farm with an area of 9 ha (3 ha each for moldboard plow, rotary hoe and moldboard plow followed by rotary hoe) was selected and it was further divided into three sub farms equally (1 ha) and used for two successive years. The experiments were designed as a randomized complete block with three replications. The sub farms were ploughed separately for moldboard plow; rotary hoe and moldboard plow followed by rotary hoe to prepare seed bed for the cultivation of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus* (Jabro et al., 2009). The summer tillage with moldboard plow; rotary hoe and moldboard plow followed by rotary hoe was performed with a definite interval of 15 days, that is, twice a month and continued for three consecutive months before seeding of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus* in these agricultural farms.

Analysis of soil characteristics

The soil physical properties namely, moisture content, bulk density (BD), water holding capacity (WHC), hydraulic conductivity and microbial biomass were measured at selected depths (0-5, 5-10, 10-15 and 15-20 cm) separately before sowing of potato (*S. tuberosum*), carrot (*D. carota* subspecies *sativus*) and radish (*R. sativus*) during 2012 to 2013. Soil was collected using a soil core sampler from each sub farms at the selected depth. The soil cores were used to measure moisture content, BD and WHC from oven dried undisturbed soil cores as a mass of oven dried soil per volume of the core (Kumar and Chopra, 2010). Particle size distribution for each core at each depth was determined using the hydrometer method (Kumar and Chopra, 2010). The soil hydraulic conductivity was measured following the methods of Osunbitan et al. (2005). However, soil microbial biomass was estimated following the standard methods (Elcio et al., 2003).

Cultivation practices of vegetables

The seeds of potato (*S. tuberosum*), carrot (*D. carota* subspecies *sativus*) and radish (*R. sativus*) were procured from Indian Agricultural Research Institute (IARI), Pusa, New Delhi and sterilized with 0.01% mercuric chloride and was soaked for 12 h. The seeds were initially sown in each sub farm using the seed rate for potato (3000 Kg ha^{-1}), carrot (4 Kg ha^{-1}) and radish (10 Kg ha^{-1}). NPK was applied at the rate of 120:60:60 Kg ha^{-1} and used in the region prescribed by Indian Council of Agriculture Research (ICAR), New Delhi. During the cultivation practices of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus*, the species of weeds were identified using the manual of Botanical Survey of India (BSI, 2012). The weeds were controlled by using non-selective herbicide (Butachlor 50% EW), and in other treatments they were controlled by a combination of herbicides (Butachlor 50% EW and Atrazine 50%) during the cultivation period of these crops. The necessary agronomic practices like irrigation, fertilization, hoeing, etc., were performed timely as per cultivation guidelines suggested by ICAR, New Delhi.

Statistical analysis

The values reported here are the means of six replicates. Means were separated using the least square means test at a significant level of $P<0.05$/$P<0.01$. Data were tested at different significant levels using one-way ANOVA to determine the difference between soil properties, weeds abundance and parameters of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus* after summer tillage using moldboard plow, rotary hoe and moldboard plow followed by rotary hoe. The treatment was considered as the fixed effect; replication was considered as the random effect; and soil depth was considered as the repeated measured variable. A Duncan's test was used to compare the mean values when a significant variation was highlighted.

RESULTS AND DISCUSSION

Influence of summer tillage on soil characteristics

Tillage affected the soil characteristics in many ways (Mirás-Avalos et al., 2011; Kabir et al., 2013). Generally, when a soil is cultivated or tilled, the soil aggregates are broken up and aerated. This exposes soil organic matter, speeds up the breakdown of soil organic matter, and is harmful to soil structure (Campiglia et al., 2010; Mirás-Avalos et al., 2011). Cultivation that mixes surface soil with subsurface soil will lead to a dilution of organic matter and it also reduces the incidence of soil borne disease to the crops by decreasing the soil microbial population and their diversity (Jabro et al., 2009; Luna et al., 2012; Kabir et al., 2013).

During the present investigation, ANOVA analysis of data indicated that the summer tillage using moldboard plow, rotary hoe and moldboard plow followed by rotary hoe significantly ($P<0.05$/$P<0.01$) affected the soil moisture content, WHC, hydraulic conductivity and soil microbial biomass (Table 1). Moreover, soil moisture content, WHC, hydraulic conductivity and soil microbial biomass was also recorded to be significantly ($P<0.05$/$P<0.01$) different at various depths (0-5, 5-10, 10-15 and 15-20 cm). The interaction of summer tillage with moldboard plow (STMP), summer tillage with rotary hoe (STRH) and soil depth (D) also showed significant effect on soil

Table 1. ANOVA for effect of summer tillage on soil characteristics used for the cultivation of different vegetables.

Source		Moisture content	Bulk density	Water holding capacity	Hydraulic conductivity	Microbial biomass	Weeds species
Summer tillage (ST)	Moldboard plow (STMP)	*	ns	*	*	**	*
	Rotary hoe (STRH)	*	ns	*	**	**	*
	Moldboard plow followed by rotary hoe	*	ns	*	**	**	*
Depth (D)	0-5	*	ns	*	**	**	*
	5-10	*	ns	*	**	**	*
	10-15	*	ns	*	**	**	*
	15-20	*	ns	*	**	**	*
Interaction STMP × STRH × D		*	ns	*	**	**	*

ns, *, ** are non-significant or significant at P≤0.05 or P≤0.01 level of ANOVA.

Table 2. Effect of summer tillage on soil characteristics used for the cultivation of different vegetables.

Tillage		Moisture content (%)	Bulk density (g cm^{-3})	Water holding capacity (%)	Hydraulic conductivity (µm s^{-1})	Microbial biomass (µg g^{-1})
Summer tillage with moldboard plow		46.30^{a}*	1.38ns	54.80^{ab}*	10.66^{ab}**	268.95^{ab}**
Summer tillage with rotary hoe		48.95^{a}*	1.37ns	45.60^{ab}*	8.78^{a}**	246.70^{ab}**
Summer tillage with both moldboard plow and rotary hoe		47.50^{a}*	1.36ns	48.12^{ab}*	8.98^{a}**	234.80^{ab}**
Depth (cm)	0-5	50.77^{ab}*	1.38ns	46.20^{ab}*	12.80^{ab}**	280.75^{ab}**
	5-10	48.32^{b}*	1.36ns	45.74^{ab}*	9.56^{ab}**	276.90^{ab}**
	10-15	44.30^{ab}*	1.35ns	42.80^{b}*	6.23^{b}**	264.30^{ab}**
	15-20	38.89^{ab}*	1.35ns	40.19^{b}*	5.78^{b}**	256.80^{ab}**
Analysis of variance P>F						
Summer tillage (ST)		6.78233	1.42312	6.72343	15.62334	52.44353
Soil depth (D)		6.67324	138243	5.62334	28.64353	21.23914
ST × D		5.45213	2.7823	5.89342	20.36742	19.42762

ns, *, ** are non-significant or significantly different at P≤0.05 or P≤0.01 level of ANOVA.

characteristics used for the experiments. It was observed that the soil moisture content (50.77 to 38.89%), BD (1.38 to 1.35 g cm^{-3}), WHC (46.20 to 40.19%), hydraulic conductivity (12.80 to 5.78 µm s^{-1}) and microbial biomass (280.75 to 256.80 µg g^{-1}) were decreased at different depths after summer tillage using moldboard plow followed by rotary hoe (Table 2). The reduction in BD, WHC and hydraulic conductivity after summer tillage may be attributed to the disturbance of soil macropores during the moldboard plow and moldboard plow followed by rotary hoe. Similar findings were reported by Jabro et al. (2009), that the long term summer tillage decreased the soil physical properties like BD, WHC and hydraulic conductivity under dryland conditions in northeastern Montana. Soil microbial biomass plays a significant role in soil fertility. In the present study, soil microbial biomass was decreased due to summer tillage practices and the findings are in line with Andrade et al. (2003) that reported the decrease in soil microbial biomass after summer tillage due to disturbance of soil structure.

Influence of summer tillage on weeds diversity

More specifically, tillage include seed bed formation, stale seed bed formation, compaction alleviation, fracturing of soil crusts, severing/dessication of weeds, maceration of biofumigant cover crops, stimulation of soil biology, and harvesting of root crops (Andrade et al., 2003; Kumar and Chopra, 2013). During no-till conditions, weeds residue increases and promotes germination of weeds. It was observed that the large seeded and deep rooted weeds decrease in populations in no-till shift, while the small seeded and shallow rooted ones increase in populations. These factors make no-till operations and moldboard plough following rotary hoeing for weeds control a good match. Optimum effectiveness of moldboard ploughing and hoeing for weeds control can be achieved in hot and sunny time of the day (De Sanctis et al., 2012; Kumar and Chopra, 2013).

In the present investigation, a total of 65 species of weeds were identified. It was observed that summer tillage using moldboard plow (STMP) significantly (P<0.01) decreased the weeds population and weeds species compared to summer tillage using rotary hoe (STRH). It is interesting to note that summer tillage using moldboard plow followed by rotary hoe more effectively reduced the number of weeds species and their population (Table 3). This is in conformity with the result which shows that the moldboard plow completely uproots the weeds through turning of the soil. Moreover, the seed of weeds reached below the soil and can not germinate easily (Campiglia et al., 2010). The findings are in accordance with Kumar and Chopra (2013) who reported that the summer tillage and spring tillage significantly decreased the number of weeds species and their abundance during the cultivation of wheat in Northern Great Plains of Ganga River in India. Similarly, Sharma et al. (2004) also investigated that summer tillage significantly reduced the weeds population and increased the productivity of spring wheat in rice-wheat system of North Western Indian plains. Moreover, Douglas et al. (2009) reported that the tillage practices were found to be effective in the control of weeds population and weeds diversity. During the present investigation, the most frequently recorded weeds were *Ageratum houstonianum*, *Asphodelus tenuifolius, Cassia absus, Carthamus oxyacantha, Chenopodium album, Convolvulus arvensis, Cynodon dactylon, Desmostachya bipinnata, Echinops echinatus, Fumaria indica, Gnaphalium coarctatum, Lathyrus aphaca, Portulaca oleracea, Sonchus oleraceus* and *Vicia sativa* after the summer tillage using moldboard plow followed by rotary hoe (Table 3). The occurrences of these weeds species are likely due to the fact that these weeds pose problems in their eradication as they regrew from underground parts (Peltzer et al., 2009). Although herbicides decreased the weeds diversity, it was observed that the underground root of the weeds regenerate them. In addition to that summer tillage, the tillage reduced the compaction of the soil and decreased the weeds diversity due to loosening of the soil from the roots of the weeds (Kumar and Chopra, 2013). Therefore, tillage affects weeds by uprooting, dismembering and burying them deep enough to prevent emergence, by changing the soil environment and inhibiting the weeds germination and establishment, and by moving their seeds vertically and horizontally (Peltzer et al., 2009; Kumar and Chopra, 2013).

Influence of summer tillage on agronomic attributes of vegetables

Tillage improves the soil characteristics particularly preparation of good seedbed, elimination of weeds and as a result it affects the agronomical attributes like seed germination, seedling growth and crop yield (Kabir et al., 2013; Kumar and Chopra, 2013). In the present study, the ANOVA analysis on data showed that summer tillage using moldboard plow followed by rotary hoe significantly (P<0.05/P<0.01) affected the plant height, dry weight, chlorophyll content and crop yield of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus* (Table 4 and Figures 1-5). The interaction of summer tillage with moldboard plow (STMP), summer tillage with rotary hoe (STRH) more significantly increased the plant height, dry weight, chlorophyll content and crop yield of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus* (Figures 1-5). The LAI of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus* was observed to be insignificantly different with summer tillage practices using moldboard plow, rotary hoe and a combination of moldboard plow followed by rotary hoe. Dry weight of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus* was also recorded to be insignificantly (P>0.05) different with summer tillage using moldboard plow, while the interaction of moldboard plow and rotary hoe showed significant effect (P<0.05) on dry weight of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus* (Table 4). The findings are in conformity with those of Kabir et al. (2013) who reported that the leaf area and crop yield of Garlic (*Allium sativum* L.) was increased significantly due to tillage practices. Kumar and Chopra (2013) also reported that summer tillage significantly increased the plant height, chlorophyll content, leaf area index (LAI) and crop yield of wheat (*Triticum aestivum* L.). It has been reported that tillage triggers the decomposition of organic matter and the release of nutrients, and mixes nutrients throughout topsoil and improves the seedling, vegetative, fruiting and maturity stages of the crop plants grown in the soil (De Sanctis et al., 2012; Kumar and Chopra, 2013). Furthermore, changes in the soil compactness influence the hydraulic and thermal properties and aeration of soils that determine mass and energy flow and, as a result, growth of roots and crop yield of the cultivated crops (Kumar and Chopra, 2013).

Conclusions

The present study concluded that summer tillage using

Table 3. Effect of summer tillage on weeds species in different vegetables.

Weed species	Family	Summer tillage with moldboard plow	Summer tillage with rotary hoe	Summer tillagewith moldboard plow followed by rotary hoe
Acanthospermum hispidum (DC)	Asteraceae	×	√	×
Ageratum conyzoides (L.)	Asteraceae	×	×	×
Ageratum houstonianum (Mill.)	Asteraceae	√	√	√
Alhagi pseudalhagi (M. Bieb.)	Fabaceae	×	×	×
Alternanthera pungens (Kunth)	Amaranthaceae	×	×	×
Argemone maxicana (L.)	Papaveraceae	×	√	×
Amaranthus viridis (L.)	Amaranthaceae	×	×	×
Anagallis arrensis (L.)	Primulaceae	×	×	×
Asphodelus tenuifolius (Cav.)	Liliaceae	√	√	√
Avena fatua (L.)	Poaceae	×	×	×
Avena ludoviciana (L.)	Poaceae	×	×	×
Bidens pilosa (L.)	Asteraceae	×	√	×
Blainvillea acmella (L.)	Asteraceae	×	×	×
Blumea eriantha (DC)	Asteraceae	×	×	×
Blumea obliqua (L.)	Asteraceae	×	×	×
Cassia absus (L.)	Caesalpiniaceae	√	√	√
Cassia obtusifolia (L.)	Caesalpiniaceae	×	×	×
Cannabis sativa (Linn.)	Cannabinaceae	×	×	×
Carthamus oxyacantha (M. Bieb.)	Asteraceae	√	√	√
Celosia argentea (L.)	Amaranthaceae	×	√	×
Chamaesyce hirta (L.)	Euphorbiaceae	×	×	×
Chamaesyce indica (Lam.)	Euphorbiaceae	×	×	×
Chenopodium album (L.)	Amaranthaceae	√	√	√
Chenopodium murale (L.)	Chenopodiaceae	×	×	×
Cichorium intybus (L.)	Asteraceae	×	×	×
Cirsium arvense (L.) Scop.	Asteraceae	×	×	×
Chamaesyce hirta (L.)	Euphorbiaceae	×	√	×
Chamaesyce indica (Lam.)	Euphorbiaceae	×	×	×
Cleome monophylla (L.)	Cleomaceae	×	×	×
Convolvulus arvensis (L.)	Convolvulaceae	√	√	√
Conyza bonariensis (L.)	Asteraceae	×	×	×
Corchorus aestuans (L.)	Tiliaceae	×	×	×
Corchorus tridens (L.)	Tiliaceae	×	√	×
Cronopus didymus (L.) Sm.	Brassicaceae	×	×	×
Cynodon dactylon (L.) Pers.	Poaceae	√	√	√
Cyperus rotundus (L.)	Cyperaceae	×	×	×
Desmostachya bipinnata (L.) Stapf.	Poaceae	√	√	√
Dinebra retroflexa (Vahl)	Poaceae	×	×	×
Echinochloa colona (L.)	Poaceae	×	×	×
Echinops echinatus (Roxb.)	Asteraceae	√	√	√
Emilia sonchifolia (L.)	Asteraceae	×	×	×
Euphorbia cyathophora (L.)	Euphorbiaceae	×	×	×
Euphorbia jelioscopia (L.)	Euphorbiaceae	×	√	×
Flaveria trinervia (Spreng)	Asteraceae	×	×	×
Fumaria indica (L.)	Fumariaceae	√	√	√
Fumaria parviflora (Lam.)	Fumariaceae	×	×	×
Galinsoga parviflora (Cav.)	Asteraceae	×	×	×
Gnaphalium coarctatum (Willd)	Asteraceae	√	√	√
Gnaphalium polycaulon (Pers.)	Asteraceae	×	×	×
Heliotropium europaeum (L.)	Boraginaceae	×	×	×
Lathyrus aphaca (L.)	Fabaceae	√	√	√
Malva parviflora (L.) William	Malvaceae	×	×	×
Medicago denticulate (Willd.)	Fabaceae	×	√	×
Melilotus alba (L.)	Fabaceae	×	×	×
Phalaris minor (Retz.)	Poaceae	×	√	×
Poa annua (L.)	Poaceae	×	×	×
Polygonum plebejum (R. Br.)	Polygonaceae	×	×	×
Portulaca oleracea (L.)	Portulacaceae	√	√	√
Rumex dentatus (L.)	Polygonaceae	×	×	×
Rumex retroflex (L.)	Polygonaceae	×	√	×
Scandix pecten-veneris (L.)	Apiaceae	×	×	×
Solanum nigrum (L.)	Solanaceae	×	×	×

Table 3. Cont'd

Sonchus oleraceus (L.)	Asteraceae	√	√	√
Spergularia rubra (L.) C. Presl.	Caryophyllaceae	×	×	×
Vicia sativa (L.)	Papilionaceae	√	√	√

LSD, 0.684 and 0.0536 at P<0.05 and P<0.01 level respectively; √, present; ×, absent.

Table 4. ANOVA for effect of summer tillage on agronomical characteristics of different vegetables.

Vegetable/parameter		Summer tillage with moldboard plough (STMP)	Summer tillage with rotary hoe (STRH)	Interaction of STMP×STRH
S. tuberosum	Plant height	**	*	**
	Dry weight	ns	*	*
	Chlorophyll content	*	*	*
	LAI	ns	ns	ns
	Crop yield	**	*	**
D. carota	Plant height	**	*	**
	Dry weight	ns	ns	ns
	Chlorophyll content	*	*	*
	LAI	ns	ns	ns
	Crop yield	**	*	**
R. sativus	Plant height	**	*	**
	Dry weight	ns	*	*
	Chlorophyll content	*	*	*
	LAI	ns	ns	ns
	Crop yield	**	*	**

* and ** are significant at P≤0.05 or P≤0.01 level of ANOVA, respectively.

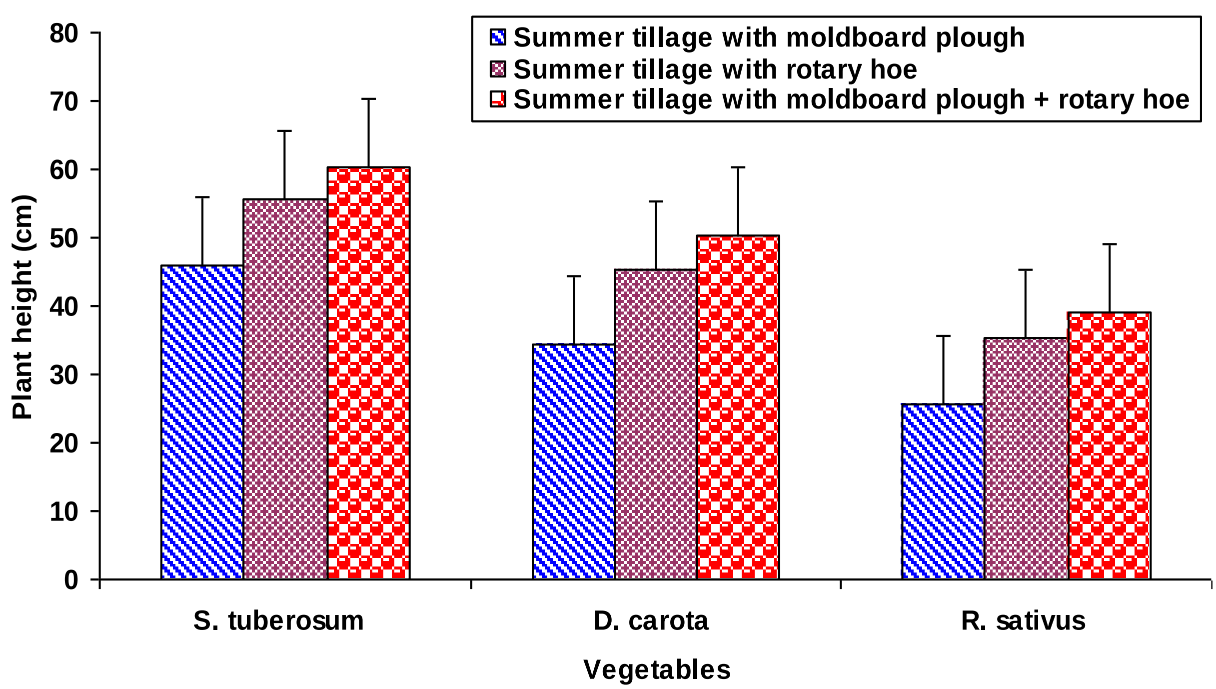

Figure 1. Effect of summer tillage on plant height of different vegetables. The data represent the mean of three replicates ± SE.

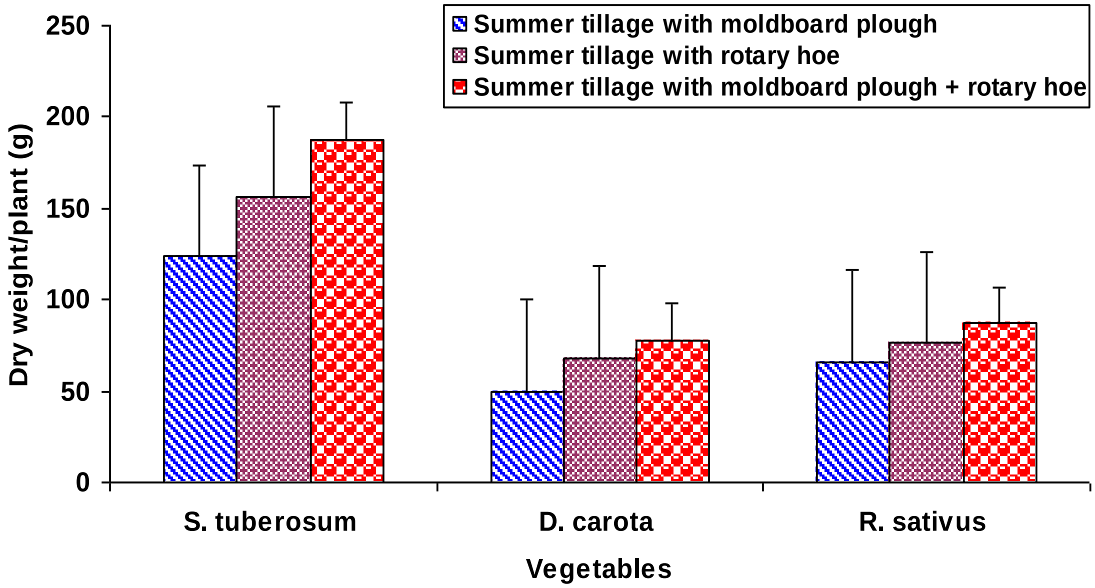

Figure 2. Effect of summer tillage on dry weight of different vegetables. The data represent the mean of three replicates ± SE.

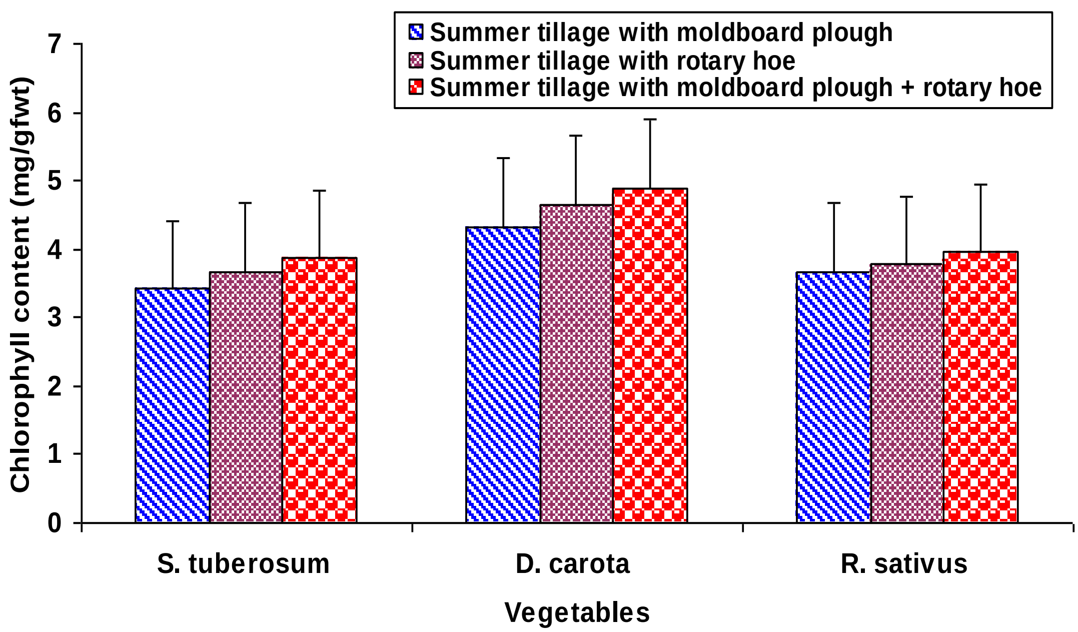

Figure 3. Effect of summer tillage on chlorophyll content of different vegetables. The data represent the mean of three replicates ± SE.

moldboard plow and rotary hoe separately and in combination significantly ($P<0.05$) affected the soil characteristics like moisture content, BD, WHC, hydraulic conductivity and microbial biomass. The summer tillage using moldboard plow followed by rotary hoe was found to be effective to control the weeds population and weeds diversity in comparison to moldboard plow and rotary hoe when used separately. Moreover, the combination of moldboard plow and rotary hoe significantly ($P<0.05$/$P<0.01$) increased the plant height, dry weight, chlorophyll content, LAI and crop yield of *S. tuberosum*, *D. carota* subspecies *sativus* and *R. sativus* when used for seed bed preparation. Therefore, seed bed must be prepared using summer tillage with moldboard plow and then rotary hoe to decrease the number of weeds species and increase the agronomical attributes of *S. tuberosum*,

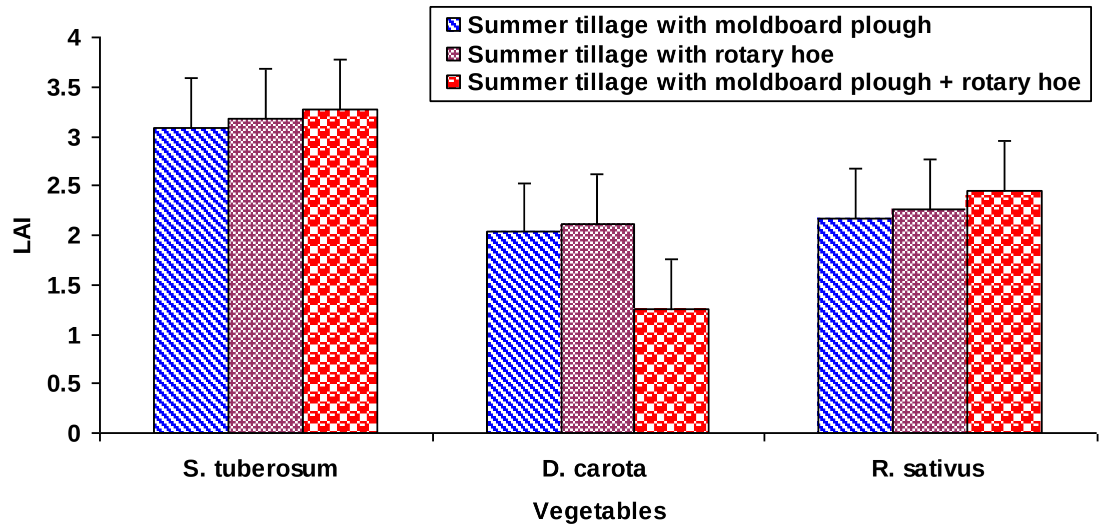

Figure 4. Effect of summer tillage on LAI of different vegetables. The data represent the mean of three replicates ± SE.

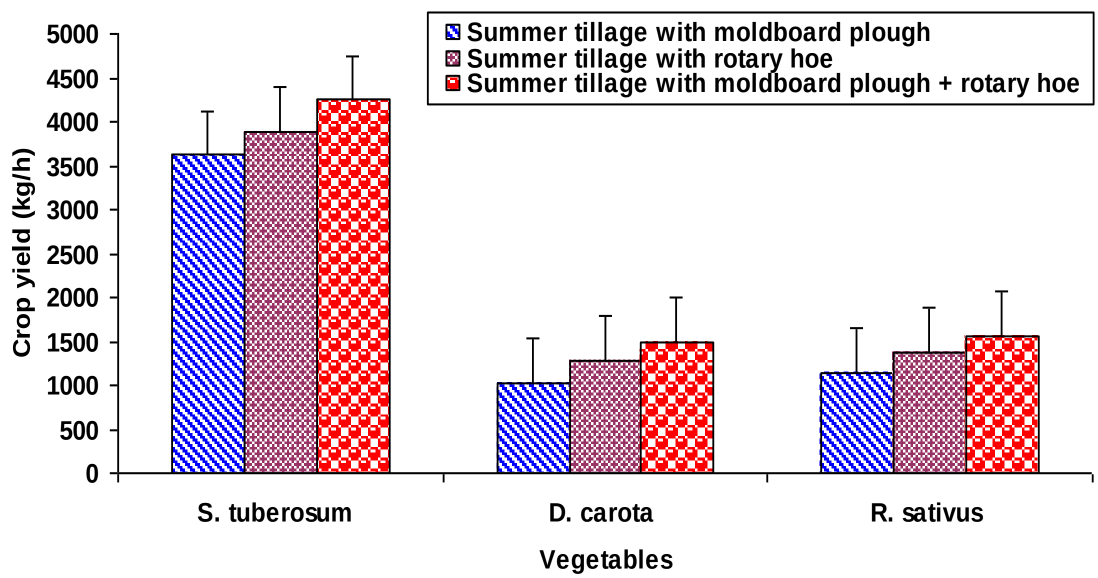

Figure 5. Effect of summer tillage on crop yield of different vegetables. The data represent the mean of three replicates ± SE.

D. carota subspecies *sativus* and *R. sativus.* Further studies should be carried out on the use of summer tillage using the combination of moldboard plow and then rotary hoe in different climatic regions to cultivate various agricultural crops.

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