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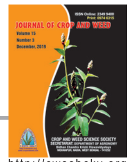

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Influence of organic weed management practices on phyto-sociology and diversity of weeds in maize-pea cropping system

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ABSTRACT

The knowledge of the impact of management practices used in each agricultural production system on the ecological interactions between commercial crops and weed populations can assist in the development of specific and sustainable management strategies. A study was carried out during 2018-19 (rabi – pea crop) to 2019 (kharif - maize crop) at Agronomy farm, Palampur (H.P) under an ongoing trial of AICRP-WM (All India Coordinated Research Project on Weed Management) commenced since kharif 2016. Ten treatments were tested including: T_1: hoeing; T_2: stale seed bed (SSB) + hoeing; T_3: raised stale seed bed (RSSB) + hoeing; T_4: mulch; T_5: SSB + mulch; T_6: RSSB + mulch; T_7: intercropping; T_8: crop rotation; T_9: intensive cropping and T_{10}: chemical check for weed management. The experiment was performed in a randomized block design with three replications. The objective of this study was to evaluate the phytosociology of the weed communities in maize and pea in different seasons, emphasizing on the relative importance of weeds and their biomass. A phytosociological analysis of the weeds was performed at monthly interval for different seasons. The dominant weed species in pea crop were Stellaria media and Phalaris minor with Importance Value Index (IVI) of 31.9 and 30.9, respectively. Shannon Weiner index accounting for order or abundance of a species within a sample plot was highest under RSSB+Hoeing followed by intensive cropping. The dominant weed species in maize crop were found to be Echinochloa colona, Cyperus sp. (C. iria and C.esculentus) and Commelina benghalensis having IVI of 56.4, 53.8 and 43.9, respectively. Shannon Weiner index was highest for the RSSB+hoeing followed by SSB+Hoeing and intercropping. Overall system's maize cob equivalent yield was found 10.4% higher in intensive cropping than the chemical check because of more yield from additional crops. RSSB + hoeing and intercropping resulted in comparable yields as chemical check.

***Keywords*:** Maize, pea, weeds, weed management, organic, cropping system

Phyto-sociological surveys in agro-ecosystems are undertaken in relation to study the relationships between weed plant populations and different crops and cropping systems. Maize based cropping system is one of the prevalent system's followed in the North-western hill states of India. Maize, a crop of vital importance, is mostly grown under rainfed conditions in Himachal Pradesh where 70-75% area is rainfed. In Himachal Pradesh, maize occupies an area of 286.78 thousand hectares producing around 725.55 thousand tonnes of grain with a productivity of 2530 kg ha^{-1} (Anonymous, 2020). Weed menace becomes a challenging task for farmers and relying on chemicals is least liked by farmers in Himachal seeing the human health constraints, soil health and environment pollution constraints associated with it. So, managing weeds is an important practice which not only requires careful planning of the cropping system, but also seeks to utilize various biological and ecological processes in the field to give crops an advantage over weeds. In case of organic crops, some additional practices such as mechanical and other control measures are usually needed to protect the crops from adverse effect of weeds. This holds true especially in the case of vegetables where production practices are such, that they lead to natural plant succession in the earlier stages and therefore, it becomes necessary to elicit the emergence of pioneer plants that are considered as weeds. People prefer growing vegetables in the hills due to shorter growing season and cooler nights. Garden pea is taken as a remunerative crop in the hilly state. Pea is cultivated in 23.65 thousand ha area with production of 287.2 thousand MT (Horticulture Statistics at a Glance, 2019. However, major constraint in pea production is the preponderance of weeds which interfere with the crop and cause huge losses in yield (Rana *et al*., 2004) and hand weeding is the most commonly adopted method of weed control by farmers. If we carry out prophylactic measures, managing weeds no longer remains a cumbersome process. That is why phyto-sociology studies should be carried out.

The phyto-sociological studies can help to determine the periods of control and/or coexistence between crops and weeds, being helpful in the determination of species which are prevalent in the different periods of crop growth (Silva *et al.*, 2018). Phyto-sociological attributes

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in the present study were studied based on seasonal observations. To study the diversity of species that constitute the plant community, techniques are adopted in order to measure the importance of a particular species in that place; for that, it is necessary to know the local floristic composition and its structure (number of species and frequency of occurrence). In order to evaluate the diversity of species, we use different population indices as for dominance, frequency and density, in an absolute or relative way (Gluguieri-Caporal, 2010). Based on data about density, dominance and frequency, Curtis and Mcintosh (1957) introduced the importance value index (IVI), defined as the sum of the relative values of density, dominance and frequency indices. Based on the IVI, it becomes possible to compare the "ecological weights" of the species of the experiment, in which similar values indicate a situation of stand equality in terms of composition, structure, site and dynamics (Lamprecht, 1990). Therefore with the help of such studies, one can devise management practices accordingly in order to check weed population because weeds always accompany arable farming and show changes according to time and space. Researchers, botanists, farmers, advisors, herbicide manufacturers and other industry players engaged in weed control can get rationale spatial impressions of trends in the weed vegetation by phytosociological studies (Hanzlik and Gerowitt*,* 2016). Hence, this study for efficient weed management in maize-pea cropping system was conducted to test the hypothesis that scientifically monitored organic weed management practices are equally or more efficient than inorganic practices.

MATERIALS AND METHODS

The study was conducted on an on-going experiment which commenced from *kharif* 2016. Earlier the crop sequence was maize – garlic in 2017 which was changed to maize – peas in the present study from *rabi* 2018-19.The experiment was conducted in randomized block design with three replications under All India Coordinated Research Project on Weed Management (AICRP-WM) at the research farm of Department of Agronomy, CSK HP Krishi Vishvavidyalaya, Palampur (H.P) located at 32°6′ N latitude, 76°3′ E longitude and 1290 m above mean sea level lying in North-West Himalaya in the Palam Valley of Kangra district of Himachal Pradesh, India. Soils are silty clay loams, low in organic carbon and available N, high in available P and medium in available K.

Ten treatments were tested including: T_1: Maize- one hoeing followed by earthing up at knee high stage in maize and in pea- hoeing (twice) 30 and 45 days after sowing ; T_2: stale seed bed (SSB) + hoeing; T_3: raised stale seed bed (RSSB) + hoeing; T_4: mulch (*Lantana* at the rate of 5t ha^{-1}) ; T_5: SSB + mulch; T_6: RSSB + mulch; T_7: intercropping(soybean) in maize and fenugreek in pea; T_8: crop rotation (maize-peas in the first year and soybean-sarson in the second year) ; T_9: intensive cropping and T_{10}: chemical check (atrazine (0.75 kg ha^{-1}) in maize and pendimethalin (1.0 kg ha^{-1}) in pea for weed management. The experiment was laid out in randomized block design with three replications.

Hoeing was done with the help of brush weeder at 30 and 45 DAS. Manual weeding was also performed. Operations in the stale seed bed/raised stale seed beds where one or two flushes of weeds were removed before sowing the crops were initiated immediately after the harvest of the previous crop. The flush of weeds which appeared in these false seed beds was destroyed by cultivation. Mulching was done using *Lantana camara* twigs mixed with grass straw from the nearby wasteland and forests that were collected and used as a mulching material at the rate of 5t ha^{-1}. *Lantana camara* is a bushy wasteland weed, growing fastly in hilly regions and is known to show good results for improving soil health when incorporated as mulch. Intercropping with soybean in case of maize and fenugreek in pea/garlic was done in order to check weed growth and get additional yields. The concept of rotating crops with different life cycles was used, as earlier in 2017 -18 *rabi* season garlic was sown which was later rotated by pea. In case of intensive cropping, incorporation of pulse- soybean, oilseed- brown sarson, green manure crop- buckwheat were taken up. Herbicides *viz*., pendimethalin (1.0 kg ha^{-1}) in pea and atrazine (0.75 kg ha^{-1}) in maize were used in chemical control treatments. The values of parameters in other treatments were compared with chemical check and it worked as a control for treatments. Pea variety "GS 10" was sown on 5th November 2018, harvested on 28th , 6th April, 2019 (gave two pickings) and maize variety 'Kanchan hybrid' was sown 28th May 2019 and harvested on 29th August, 2019. Before sowing, seed treatment with beejamrit and *Trichoderma* was done. Only one pre-sowing irrigation was given to maize. However, in pea four successive irrigations were given during entire crop growth period. Thereafter, the crop met its water requirement through rainfall. Application of panchgavya and vermiwash were done as additional nutrient supplements. In each plot, data on weed count and dry weight were recorded species-wise at monthly interval and at harvest from 50 cm × 50 cm quadrate from two places in each plot. The weed count and dry weight so obtained were converted to number and grams per square metre, respectively by multiplying the average count and dry weight of the weeds with factor 4.

During *rabi* (2018-19) maximum temperature ranged between 25.5 to 31°C (13th and 18th

meteorological week, respectively). The minimum temperature ranged between 0 and 7.5°C (52^{nd} and 6^{th} meteorological week, respectively). A total of 639.6 mm rainfall was occurred during the entire 2018-19 *rabi* season. During *kharif* 2019, the maximum temperature ranged between 31.0 to 35.5°C (22^{nd} and 27^{th} meteorological week, respectively). The minimum temperature was between 16.5 to 23.5°C (25^{th} and 23^{rd} meteorological week, respectively). Total amount of rainfall received was 1366.8 mm. During the *kharif* season, the highest amount of rainfall (266.8 mm) was received in 33^{rd} meteorological week.

The formulae to calculate for weed phytosociology parameter, i.e., seasonal average density (No. m^{-2}), frequency (%), abundance, IVI (Importance Value Index) of weed species are given as follows:

$$\text{Density} = \frac{\text{Total number of individuals of a species in all quadrates}}{\text{Total number of quadrates studied}}$$

$$\text{Frequency } (\%) = \frac{\text{Total number of quadrates in which the species occurred}}{\text{Total number of quadrates studied}}$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrates}}{\text{Total number of quadrates in which the species occurred}}$$

In calculating IVI, the percentage values of the relative frequency, relative density and relative abundance are summed up together and this value is designated as the Importance Value Index or IVI of the species.

Weed diversity indices

Species richness (D)

Species richness is a measure of the number of different kinds of organisms present in a particular area. It was calculated in accordance with the equations cited by Booth *et al*. (2003). It was calculated as follows:

$D = S/\sqrt{N}$, where S is equal the numbers of different species and N is total number of individual organisms in a sample.

Shannon Weiner index

Shannon Weiner index (H) accounts for both abundance and evenness of the species present. It was calculated in accordance with the equations cited by Booth *et al*. (2003).The proportion of species i relative to the total number of species (pi) is calculated, and then multiplied by the natural logarithm of this proportion (lnpi). The resulting product is summed across species and multiplied by -1:

$$H = -\Sigma\left[pi\left(\ln pi\right)\right]$$

Maize equivalent yield = Cm + Cp X Pp/ Pm

Where Cm and Cp are crop yield of maize and pea, respectively and Pp and Pm are price of pea and maize, respectively.

Statistical analysis

Data on weeds were analyzed after transformation to the square-root scale ($\sqrt{X + 0.5}$) to account for the non-normality of distribution. All data were analyzed by ANOVA, and the least significant difference (LSD) values at 5% level of significance were calculated and used to test significant differences between treatment means.

RESULTS AND DISCUSSION

Pea

Phyto-sociology of *rabi* season weeds

The phyto-sociological studies helps us to determine the periods of control i.e. when the crops and weeds are co-existing. Thus these are helpful in the determination of species which are most important in the different periods of growth of the crop.

Relative Abundance (RA), Relative Density (RD) and Relative Frequency (RF)

Stellaria media was the most abundant weed at 90 DAS in Mulch followed by intercropping and crop rotation versus other treatments. *Poa annua* was the most abundant weed in mulch treatment. *Stellaria media* and *Phalaris minor* were the most densely present weeds in mulch, RSSB + hoeing, RSSB + mulch, intercropping, crop rotation and chemical check treatments in pea. Greater density of *Vicia sativa* was in hoeing, SSB + mulch, crop rotation and chemical check treatments. *Vicia sativa* is a winter annual weed. Its growth habit makes it difficult to control. Addition of vermicompost might have lead to soil enrichment which caused germination of more weeds, hence, maximum population of these weeds was seen. *Tulipa asiatica* was most predominant in chemical check and RSSB + mulch treatments followed by intercropping. Singh and Angiras (2004) also observed that *Coronopus didymus*, *Ranunculus arvensis*, *Bidens pilosa*, *Polygonum alatum* and *Vicia* sp. collectively constituted 84.6% and *Phalaris minor* constituted 15.4% of total weed density at

Table 1: Effect of treatments on relative abundance (%) of different weed species in pea

Weed species	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Overall
Alopecurus myosuroides	2.1	3.8	2.9	4.7	4.1	3.4	5.8	2.6	5.6	2.4	3.2
Anagallis arvensis	4.1	6.4	7.1	5.1	9.2	4.2	8.9	7.5	6.7	0.0	6.2
Avena ludoviciana	5.4	3.2	3.4	3.4	4.6	5.1	4.1	5.7	5.3	3.8	4.0
Bidens pilosa	3.1	3.2	1.8	3.5	2.8	5.6	3.1	0.0	5.6	0.0	2.9
Coronopus didymus	5.1	4.8	3.4	0.0	0.0	5.6	4.5	0.0	3.3	4.1	3.7
Erodium	2.1	8.6	5.4	4.0	7.4	8.4	5.8	2.0	5.6	6.1	5.2
Euphorbia heliscopia	2.1	3.6	4.9	2.5	4.6	0.0	0.0	4.9	6.4	3.6	4.4
Galinnsoga parviflora	3.1	0.0	3.0	3.0	2.8	2.8	0.0	3.0	4.4	0.0	2.7
Lathyrus aphaca	0.0	0.0	0.0	0.0	0.0	1.9	0.0	2.0	0.0	0.0	1.7
Lolium temulentum	10.5	5.2	4.5	0.0	8.7	2.8	0.0	2.0	5.6	5.1	5.5
Oxalis corniculata	3.8	7.3	4.5	4.0	3.7	4.7	4.8	6.9	7.8	10.9	4.7
Oxalis latifolia	6.2	6.0	4.5	3.8	5.2	6.5	2.9	3.9	5.1	0.0	4.4
Phalaris minor	5.1	6.7	5.4	7.4	5.9	5.3	6.9	8.1	6.3	7.5	5.6
Plantago lanceolata	2.8	0.0	2.7	2.0	2.8	0.0	0.0	4.9	2.8	0.0	2.9
Poa annua	7.5	3.7	7.4	14.1	1.8	7.6	5.3	4.4	4.2	8.7	5.4
Ranunculus sp	3.1	6.0	2.7	3.8	4.4	3.4	6.8	4.8	3.3	3.6	3.8
Rumex dentatus	0.0	0.0	5.4	4.0	3.7	0.0	0.0	0.0	0.0	0.0	3.8
Stellaria media	7.6	6.9	9.1	13.3	7.2	8.9	13.0	11.3	6.5	8.9	8.2
Tulipa asiatica	4.9	6.4	4.8	5.5	4.7	8.2	8.0	6.7	5.3	8.5	5.5
Veronica persica	4.1	4.3	3.6	3.5	3.2	4.7	4.8	5.9	0.0	4.1	3.7
Vicia hirsute	8.9	6.7	6.7	5.9	6.7	6.5	7.2	3.9	4.8	11.5	6.0
Vicia sativa	8.4	7.3	7.1	6.3	6.5	4.5	8.2	9.4	5.4	11.1	6.5

T_1- Hoeing, T_2- SSB + hoeing, T_3- RSSB + hoeing, T_4- Mulch, T_5- SSB + mulch, T_6- RSSB + mulch, T_7- Intercropping, T_8-Crop rotation, T_9- Intensive cropping, T_{10}-Chemical check

Table 2: Effect of treatments on relative density (No. m^{-2}) of different weed species in pea

Weed species	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Overall
Alopecurus myosuroides	0.4	0.7	2.3	2.8	1.5	2.3	0.9	1.3	1.3	0.5	1.4
Anagallis arvensis	1.5	6.7	4.3	6.0	13.4	3.7	6.9	7.5	9.3	0.0	6.2
Avena ludoviciana	11.1	2.9	2.7	2.0	5.0	10.0	6.3	8.5	11.1	7.6	6.5
Bidens pilosa	1.1	1.7	0.7	2.8	0.5	1.2	2.4	0.0	1.3	1.7	1.3
Coronopus didymus	1.9	2.5	3.4	0.6	0.5	3.7	2.1	0.8	2.3	2.5	2.0
Erodium	0.4	3.0	2.1	0.8	4.0	3.7	2.7	0.3	5.2	3.7	2.5
Euphorbia heliscopia	0.4	2.5	3.9	1.0	1.7	0.0	7.4	4.1	5.9	1.5	2.9
Galinnsoga parviflora	2.3	0.0	1.8	0.6	1.0	0.6	0.0	0.5	1.0	0.0	0.8
Lathyrus aphaca	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.1
Lolium temulentum	11.7	3.7	0.9	0.0	3.2	0.6	3.6	0.3	5.2	5.2	3.3
Oxalis corniculata	2.1	3.9	2.7	2.4	2.0	1.0	0.8	3.4	1.8	2.2	2.3
Oxalis latifolia	3.4	3.2	0.9	3.0	2.9	1.4	0.9	2.0	5.9	1.0	2.4
Phalaris minor	8.6	14.3	10.7	16.2	11.9	12.7	11.7	14.9	14.7	16.7	13.1
Plantago lanceolata	2.1	2.5	1.6	0.4	1.0	0.4	1.4	0.8	1.3	0.5	1.2
Poa annua	9.8	4.5	8.9	8.3	1.3	6.7	3.3	2.9	3.9	8.8	5.6
Ranunculus sp	0.6	6.4	3.2	3.0	4.0	3.7	3.2	6.4	1.5	3.7	3.7
Rumex dentatus	0.0	0.0	3.2	3.2	0.7	1.0	0.8	0.0	1.0	0.0	1.0
Stellaria media	9.9	9.8	18.3	18.4	15.8	19.4	14.2	20.6	9.0	5.4	14.4
Tulipa asiatica	7.3	10.1	8.6	7.6	7.7	10.8	13.7	6.7	6.2	13.8	9.3
Veronica persica	1.5	1.5	1.4	2.8	1.2	2.0	0.8	3.9	0.0	2.5	1.8
Vicia hirsute	8.2	5.9	5.4	8.2	7.4	8.6	5.6	2.0	3.4	9.3	6.3
Vicia sativa	15.7	14.1	12.9	10.0	13.1	5.9	11.4	12.4	8.8	13.5	11.9

Table 3: Effect of treatments on relative frequency (%) of different weed species in pea

Weed species	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Overall
Alopecurus myosuroides	1.1	1.0	4.3	3.6	2.1	3.8	1.1	3.3	1.3	1.4	2.3
Anagallis arvensis	2.2	6.2	3.2	7.1	8.3	5.1	5.3	6.6	7.6	0.0	5.2
Avena ludoviciana	12.4	5.2	4.3	3.6	6.3	11.4	10.6	9.9	11.4	13.5	8.7
Bidens pilosa	2.2	3.1	2.1	4.8	1.0	1.3	5.3	0.0	1.3	2.7	2.4
Coronopus didymus	2.2	3.1	5.3	1.2	1.0	3.8	3.2	1.1	3.8	4.1	2.8
Erodium	1.1	2.1	2.1	1.2	3.1	2.5	3.2	1.1	5.1	4.1	2.5
Euphorbia heliscopia	1.1	4.1	4.3	2.4	2.1	0.0	7.4	5.5	5.1	2.7	3.5
Galinnsoga parviflora	4.5	0.0	3.2	1.2	2.1	1.3	0.0	1.1	1.3	0.0	1.5
Lathyrus aphaca	0.0	0.0	0.0	0.0	0.0	1.3	0.0	2.2	0.0	0.0	0.3
Lolium temulentum	6.7	4.1	1.1	0.0	2.1	1.3	4.3	1.1	5.1	6.8	3.2
Oxalis corniculata	3.4	3.1	3.2	3.6	3.1	1.3	1.1	3.3	1.3	1.4	2.5
Oxalis latifolia	3.4	3.1	1.1	4.8	3.1	1.3	2.1	3.3	6.3	1.4	2.8
Phalaris minor	10.1	12.4	10.6	13.1	11.5	13.9	11.7	12.1	12.7	14.9	12.2
Plantago lanceolata	4.5	3.1	3.2	1.2	2.1	1.3	2.1	1.1	2.5	1.4	2.3
Poa annua	7.9	7.2	6.4	3.6	4.2	5.1	4.3	4.4	5.1	6.8	5.5
Ranunculus sp	1.1	6.2	6.4	4.8	5.2	6.3	3.2	8.8	2.5	6.8	5.1
Rumex dentatus	0.0	0.0	3.2	4.8	1.0	1.3	0.0	0.0	1.3	0.0	1.4
Stellaria media	7.9	8.2	10.6	8.3	12.5	12.7	7.4	12.1	7.6	4.1	9.2
Tulipa asiatica	9.0	9.3	9.6	8.3	9.4	7.6	11.7	6.6	6.3	10.8	8.9
Veronica persica	2.2	2.1	2.1	4.8	2.1	2.5	1.1	4.4	0.0	4.1	2.5
Vicia hirsute	5.6	5.2	4.3	8.3	6.3	7.6	5.3	3.3	3.8	5.4	5.5
Vicia sativa	11.2	11.3	9.6	9.5	11.5	7.6	9.6	8.8	8.9	8.1	9.7

Table 4: Effect of treatments on Important Value Index of different weed species in pea

Weed species	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Overall
Alopecurus myosuroides	3.6	5.5	9.5	11.1	7.7	9.5	7.8	7.2	8.1	4.3	6.9
Anagallis arvensis	7.9	19.3	14.6	18.2	31.0	12.9	21.1	21.7	23.5	0.0	17.6
Avena ludoviciana	28.9	11.3	10.3	8.9	15.9	26.5	21.0	24.1	27.8	24.9	19.1
Bidens pilosa	6.5	8.0	4.6	11.1	4.3	8.1	10.8	0.0	8.1	4.4	6.6
Coronopus didymus	9.3	10.4	12.1	1.8	1.5	13.1	9.8	1.9	9.5	10.6	8.5
Erodium	4.1	9.5	3.2	14.9	6.8	12.9	10.4	14.0	3.9	15.2	8.7
Euphorbia heliscopia	3.6	13.7	9.6	6.0	14.5	14.6	11.7	3.4	15.8	13.8	10.2
Galinnsoga parviflora	9.9	0.0	8.0	4.8	5.8	4.7	0.0	4.5	6.7	0.0	5.0
Lathyrus aphaca	0.0	0.0	0.0	0.0	0.0	3.5	0.0	4.8	0.0	0.0	2.2
Lolium temulentum	28.9	13.1	6.4	0.0	14.0	4.7	7.9	3.4	15.8	17.0	12.0
Oxalis corniculata	9.2	14.3	10.3	10.0	8.8	7.0	6.7	13.6	10.9	14.5	9.5
Oxalis latifolia	13.0	12.3	6.4	11.5	11.2	9.2	5.9	9.2	17.4	2.3	9.6
Phalaris minor	23.9	33.4	26.7	36.7	29.3	31.9	30.3	35.1	33.7	39.1	30.9
Plantago lanceolata	9.4	5.6	7.5	3.6	5.8	1.7	3.5	6.8	6.6	1.8	6.4
Poa annua	25.2	15.4	22.6	26.0	7.3	19.4	12.9	11.8	13.1	24.2	16.5
Ranunculus sp	4.8	18.6	12.3	11.5	13.7	13.4	13.1	20.0	7.4	14.1	12.6
Rumex dentatus	0.0	0.0	11.8	12.0	5.4	2.3	0.8	0.0	2.3	0.0	6.1
Stellaria media	25.5	24.9	38.0	40.0	35.5	41.0	34.6	44.0	23.1	18.4	31.9
Tulipa asiatica	21.1	25.7	22.9	21.4	21.8	26.7	33.4	20.0	17.9	33.1	23.7
Veronica persica	7.9	7.9	7.1	11.1	6.5	9.2	6.7	14.2	0.0	10.6	8.0
Vicia hirsute	22.7	17.7	16.3	22.4	20.4	22.7	18.0	9.2	12.0	26.3	17.8
Vicia sativa	35.3	32.8	29.6	25.8	31.1	18.0	29.2	30.6	23.0	32.8	28.1

Table 5: Effect of treatments on diversity indices of weeds in peas

Treatment	No. of species	No. of species common as T_{10}	No. of species present in new system but absent in T_{10}	Shannon Wiener index (H)	Species richness (D)
T_1	19	17	2	2.392	1.237
T_2	19	17	2	2.598	1.102
T_3	21	18	3	2.680	1.257
T_4	20	17	3	2.538	1.264
T_5	20	17	3	2.567	1.218
T_6	20	17	3	2.509	1.343
T_7	16	14	2	2.219	1.098
T_8*	21	17	4	2.452	1.143
T_9	19	16	3	2.668	1.436
T_{10}	18	18	-	2.382	1.262
Overall	22	18	4	2.721	0.426

** Maize-pea and soybean-sarson alternatively*

Table 6: Effect of treatments on relative abundance (%) of different weed species in maize during 2019

Weed species	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Overall
Aeschynomene	2.7	5.2	2.9	3.7	1.8	1.3	1.6	2.8	1.8	2.2	2.4
Alternanthera	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.0	0.0	1.9
Commelina benghalensis	12.4	10.7	10.3	11.0	7.0	9.0	8.9	16.9	11.9	13.8	10.1
Cyperus sp	37.2	25.6	19.9	13.1	18.3	28.4	30.3	13.1	27.8	17.9	19.8
Digitaria sanguinalis	3.9	5.5	17.8	3.8	5.3	5.3	7.2	20.9	8.2	8.1	8.1
Echinochloa colona	20.1	23.7	17.0	33.5	26.4	31.6	19.3	16.8	14.3	22.0	19.7
Eleusine indica	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.2	3.0
Euphorbia geniculata	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.0
Gallinsoga parviflora	15.8	5.2	7.6	11.1	18.3	0.0	8.4	15.6	21.6	15.2	10.6
Ipomoea	0.0	1.9	0.0	7.3	0.0	0.0	0.0	4.9	2.3	2.7	3.2
Panicum distichum	0.0	3.1	4.0	0.0	2.7	4.1	8.2	1.9	2.3	5.8	3.8
Physalis minima	1.5	10.2	5.6	8.6	4.9	5.0	3.5	0.0	0.0	3.8	5.6
Polygonum alatum	6.6	8.8	14.7	8.0	15.3	15.4	11.1	7.1	9.9	5.3	8.8

Table 7: Effect of treatments on relative density (No. m^{-2}) of different weed species in maize during 2019

Weed species	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Overall
Aeschynomene	2.9	1.9	1.3	2.6	1.0	0.2	0.3	0.8	1.2	2.1	1.5
Alternanthera	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.1	0.1
Commelina benghalensis	17.1	21.8	15.4	15.5	6.9	12.9	15.4	21.6	19.4	19.7	16.7
Cyperus sp	22.8	28.4	26.9	11.1	25.8	28.5	23.4	13.1	31.6	11.4	22.3
Digitaria sanguinalis	1.8	4.1	5.3	1.1	3.0	3.0	6.9	26.7	5.3	1.3	5.4
Echinochloa colona	27.8	17.5	20.4	33.1	26.0	31.8	22.3	14.3	13.9	31.5	24.1
Eleusine indica	0.3	0.0	0.4	1.1	1.2	0.6	0.8	0.5	0.0	1.0	0.6
Euphorbia geniculata	0.0	2.0	0.5	1.7	1.5	0.0	0.8	1.0	0.8	0.0	0.8
Gallinsoga parviflora	19.4	7.7	5.7	11.0	12.8	1.6	6.5	11.1	10.5	19.4	10.5
Ipomoea	0.0	1.8	1.8	2.1	3.1	1.2	0.0	1.4	2.2	2.1	1.6
Panicum distichum	0.0	2.3	1.8	0.0	1.5	1.8	6.3	0.8	0.7	5.5	2.0
Physalis minima	0.4	7.6	5.1	7.3	2.1	2.9	2.0	0.0	1.3	1.8	3.2
Polygonum alatum	7.1	4.9	15.4	13.6	15.0	15.5	14.9	8.1	12.9	4.2	11.1

Table 8. Effect of treatments on relative frequency (%) of different weed species in maize during 2019

Weed species	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Overall
Aeschynomene	13.7	3.6	5.2	7.9	6.8	2.0	2.2	3.6	7.5	10.3	6.4
Alternanthera	2.0	0.0	0.0	0.0	0.0	0.0	2.2	1.8	0.0	0.0	0.5
Commelina benghalensis	17.6	20.0	17.2	15.9	11.9	20.0	19.6	16.4	18.9	15.5	17.2
Cyperus sp	7.8	10.9	15.5	9.5	16.9	14.0	8.7	12.7	13.2	6.9	11.7
Digitaria sanguinalis	5.9	7.3	3.4	3.2	6.8	8.0	10.9	16.4	7.5	1.7	6.9
Echinochloa colona	17.6	7.3	13.8	11.1	11.9	14.0	13.0	10.9	11.3	15.5	12.6
Eleusine indica	2.0	0.0	1.7	3.2	3.4	2.0	2.2	1.8	0.0	3.4	2.0
Euphorbia geniculata	0.0	7.3	1.7	6.3	5.1	0.0	2.2	3.6	1.9	0.0	2.9
Gallinsoga parviflora	15.7	14.5	8.6	11.1	8.5	6.0	8.7	9.1	5.7	13.8	10.2
Ipomoea	0.0	9.1	5.2	3.2	5.1	6.0	0.0	3.6	11.3	8.6	5.3
Panicum distichum	0.0	7.3	5.2	0.0	6.8	6.0	8.7	5.5	3.8	10.3	5.3
Physalis minima	3.9	7.3	10.3	9.5	5.1	8.0	6.5	0.0	3.8	5.2	6.0
Polygonum alatum	13.7	5.5	12.1	19.0	11.9	14.0	15.2	14.5	15.1	8.6	13.0

Table 9. Effect of treatments on IVI (Importance value index) of different weed species in maize during 2019

Weed species	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	Overall
Aeschynomene	19.3	10.8	9.4	14.2	9.5	3.5	4.1	7.3	10.6	14.7	10.3
Alternanthera	2.3	0.0	0.0	0.0	0.0	0.0	4.1	2.4	0.0	0.0	2.6
Commelina benghalensis	47.2	52.5	43.0	42.4	25.8	41.9	43.8	54.9	50.2	49.0	43.9
Cyperus sp	67.9	65.0	62.3	33.6	61.1	70.9	62.5	38.9	72.6	36.2	53.8
Digitaria sanguinalis	11.6	16.8	26.6	8.0	15.0	16.3	25.0	63.9	21.0	11.1	20.5
Echinochloa colona	65.5	48.5	51.2	77.7	64.3	77.3	54.7	42.0	39.5	69.0	56.4
Eleusine indica	2.3	0.0	2.1	4.2	4.6	2.6	2.9	2.3	0.0	7.6	5.6
Euphorbia geniculata	0.0	9.3	2.2	8.0	6.6	0.0	2.9	4.7	2.7	0.0	6.7
Gallinsoga parviflora	50.8	27.4	22.0	33.2	39.6	7.6	23.6	35.8	37.8	48.4	31.4
Ipomoea	0.0	12.7	7.0	12.5	8.2	7.2	0.0	9.9	15.8	13.4	10.1
Panicum distichum	0.0	12.7	10.9	0.0	11.0	11.8	23.2	8.2	6.8	21.6	11.1
Physalis minima	5.8	25.1	21.0	25.5	12.1	15.8	12.0	0.0	5.1	10.9	14.8
Polygonum alatum	27.3	19.2	42.3	40.6	42.2	44.9	41.2	29.7	37.9	18.2	32.9

Table 10. Effect of treatments on diversity indices of weeds in maize

Treatment	No. of species	No. of species common as T_{10}	No. of species present in new system but absent in T_{10}	Shannon Wiener index (H)	Species richness (D)
T_1	10	9	1	1.700	0.473
T_2	11	10	1	1.899	0.473
T_3	12	11	1	1.951	0.519
T_4	11	10	1	1.826	0.465
T_5	12	11	1	1.728	0.562
T_6	11	11	0	1.619	0.473
T_7	12	10	2	1.898	0.666
T_8	12	10	2	1.860	0.577
T_9	11	10	1	1.787	0.471
T_{10}	11	11	0	1.881	0.471
Overall	**13**	**11**	**2**	**2.011**	**0.185**

Table 11: Maize equivalent yield and gross returns from different crops under treatments during 2018-19

	Treatment	Maize equivalent yield (kg ha^{-1})		
		Rabi	***Kharif***	**System's**
T_1	Hoeing	5093	5760	10853
T_2	SSB + hoeing	12273	5781	18054
T_3	RSSB + hoeing	13546	9208	22755
T_4	Mulch	3412	5229	8641
T_5	SSB + mulch	8861	4292	13153
T_6	RSSB + mulch	12477	6510	18987
T_7	Intercropping	12750	9331	22081
T_8	Crop rotation	6366	8042	14407
T_9	Intensive cropping	15380	12816	28196
T_{10}	Chemical check	15227	10323	25550
SEm(±)		**1015**	**569**	**1260**
LSD(0.05)		**3017**	**1689**	**3744**

Palampur. The effect of weed control treatments on abundance of weed species invaded in pea during 2018-19 has been presented in Table 1.

The effect of treatments on overall average density of weed species present in pea during the winter season of 2018-19 has been shown in Table 2. *Stellaria media* followed by *Phalaris minor* were the most densely present weeds. This could be attributed to the fact that these weeds produce more number of seeds and are winter growing annuals who find congenial environment for growth in winters.

Frequency is an useful index that monitors and compares the changes occurring in plant community over time (Bonham, 2013). Frequency reflects both a species' presence or absence and how much/upto what extent it is distributed within a community. From Table 3, it is evident that *Phalaris minor* was the most frequently occurring weed in all the treatments except hoeing (T_1) and SSB + mulch (T_5) whereas *Avena ludoviciana* and *S. media* were leading and in treatments such as RSSB + hoeing (T_3), intercropping (T_7) where *P. minor* was equal to *S. media* and *T. asiatica*. Ability to produce more seeds and favourable environment with sparse rains during winters favoured for maximum growth of these weeds.

Total weed count (No. m^{-2})

The data on total weed count have been presented in Fig 1. It is evident from the Fig. 1 that weed count was least in the beginning, increased during successive months and reached maximum at the time of harvest (120 DAS) except in treatments SSB + hoeing (T_2), RSSB + hoeing (T_3) and RSSB + mulch (T_6), where total weed count was maximum at 90 DAS. It was found that intensive cropping (T_9), chemical check (T_{10}) and RSSB + mulch (T_6) had the lowest total weed count. It might have occurred because in case of intensive cropping, the field was not left fallow and always was found with a crop cover,so more competition offered to weeds by crops. In case of chemical check (T_{10}), integration of herbicides with manual weeding led to significantly decrease the total weed count. These results confirm the observations of Gopinath *et al*. (2009), who also reported hand weeding twice (30 and 60 DAS) being at par with hand weeding + mulching and stale seedbed + hand weeding resulted in significantly lower population of weeds compared to other treatments. In case of RSSB + mulch (T_6), due to application of RSSB, majority of weed seeds buried 4-6 inches below the surface and germination of those weeds that were present on the upper surface was induced which were later destroyed by subsequent tillage, by uprooting, damaging, depleting food reserves, root pruning or other injury that impoverished the population of weed seeds in soil. Mulching the top surface with 5cm layer of *Lantana* also led to suppression of weed seed bank in soil as there was very less availability of sunlight. Hence, the combined effect of RSSB + mulch led to lower down the total weed count. The results are in agreement with findings of Gopinath *et al*. (2009).

Importance value index (IVI)

IVI is a standard tool used to determine the overall importance of a species under a particular field condition when crops and weeds exist together which is obtained by summing up relative density, relative frequency and relative abundance or coverage. The dominant weed species would have high important value index. The weeds present in pea crop having highest IVI were *Stellaria media*, *Phalaris minor*, *Vicia sativa* and *Tulipa asiatica* as shown in Table 4. This could be at-

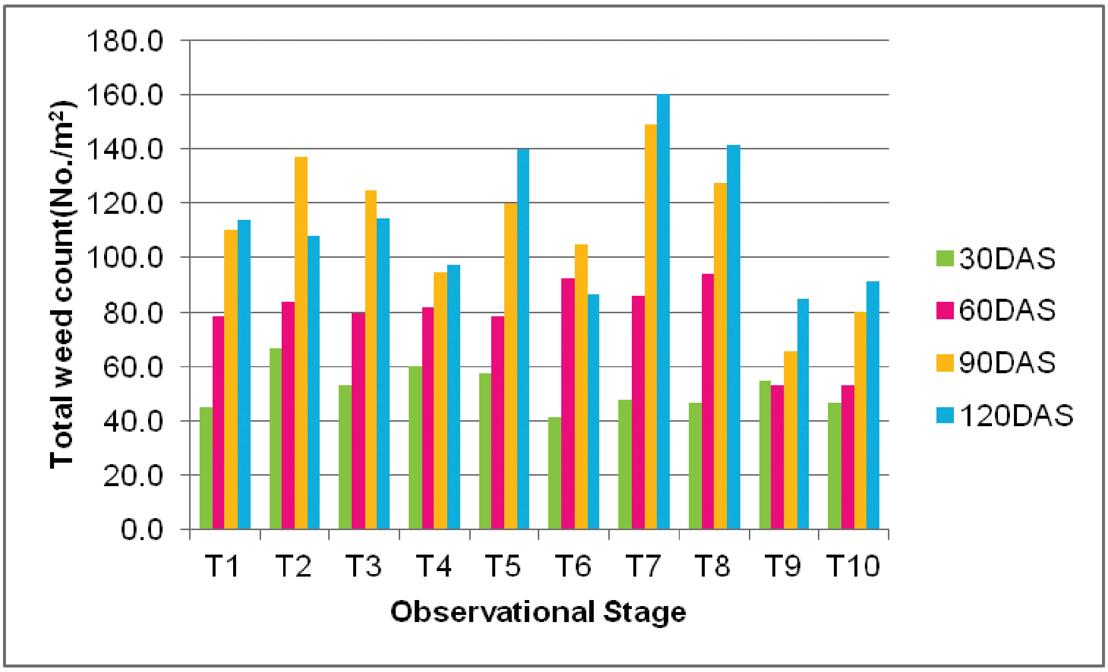

Fig. 1 : Effect of treatments on total weed count in pea (No. m^{-2})

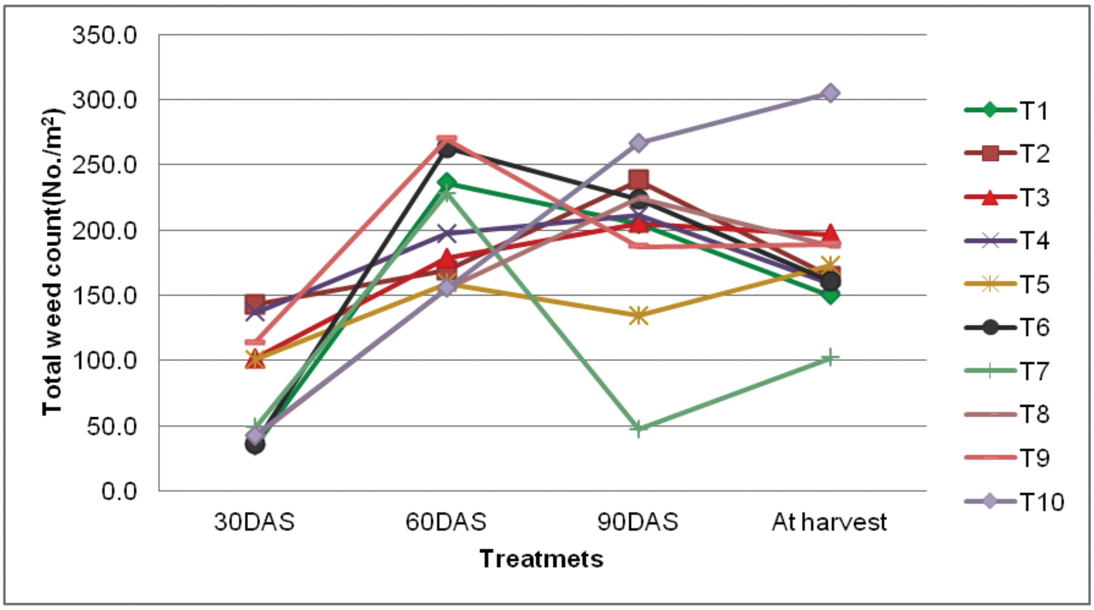

Fig. 2: Effect of treatments on total weed count (No. m^{-2}) in maize

tributed to higher seed production potential, luxuriant and aggressive growth habits of these weeds under frequent rains that occurred in February and there was poor population of fenugreek sown as intercrop which could not provide canopy for weed suppression. Unless crop canopies of all companion crops compensate each other for a better shade for the under-story, weed suppression would not be achieved to a considerable extent (Dwivedi *et al.*, 2012). At harvest stage, *Vicia hirsuta* was observed to have 37 siliqua in its plant. This, however, led to increase in their number.

Diversity indices

There were 22 weed species found growing in peas during 2018-19 in different weed control treatments. *Stellaria media* (14%), *Phalaris minor* (13%), *Vicia sativa* (12%), *Tulipa asiatica* (9%), *Vicia hirsuta* (6%), *Avena ludoviciana* (7%), *Poa annua* (6%), *Anagallis arvensis* (6%) and *Ranunculus arvensis* (4%) were the major weeds. The other weeds *viz*. *Allopecurus myosuroides*, *Bidens pilosa*, *Coronopus didymus*, *Erodium cicutarium*, *Euphorbia helioscopia*, *Galinsoga* *parviflora*, *Lathyrus aphaca*, *Lolium temulentum*, *Oxalis latifolia*, *Oxalis corniculata*, *Plantago lanceolata*, *Rumex dentatus*, and *Veronica persica* as a whole constituted 23% of the total weed flora. In 'chemical control' 18 weed species were found associated. Fourteen to eighteen weed species were common in 'chemical control' and other weed control treatments. Two to four weed species in different weed treatments were found different from 'chemical control'. Table 5 clearly indicates that with changes in cultural weed management practice, variation in infestation of weed flora occurred. Wider spacing in peas provides ample opportunities for weed infestation (Singh *et al*. 1991; Kundra *et al*. 1993) and could be one of the reasons for more weed infestation.

Shannon Weiner index was highest under RSSB + hoeing treatment (T_3) followed by intensive cropping (T_9). Lowest values of this index were obtained under intercropping (T_7) followed by hoeing (T_1) probably owing to companion cropping and hoeing which was done twice, respectively. The high number of weeds identified in this study could be attributed to the presence of a large weed seed bank in the soil that must have been deposited from previous years.

Maize

Phytosociology of *kharif* season weeds

Relative Abundance, Relative Density and Relative Frequency

The data on abundance of weed species under different treatments in maize during 2019 have been given in Table 6. A critical review of data revealed that *Cyperus* sp.(24%) and *Echinochloa colona* (22%) were the most abundant weeds in the experimental field. *Commelina benghalensis* was the next abundant after *Galinsoga parviflora*. *Alternanthera philoxeroides* was the least abundant weed. *Cyperus,* is a perennial species, with wide adaptability to many agricultural environments and with sexual and asexual reproduction capacity (Panozzo *et al*., 2009). In the beginning at juvenile stage, the species of *Cyperus* was unidentifiable and were taken together. However, at the reproductive stage, two species *Cyperus iria* and *Cyperus esculentus* were observed. The count of *Cyperus* sp. (*Cyperus iria* and *Cyperus esculentus)* was in general higher at 60 DAS. It is one of the most important weed species in the world due to its rapid reproduction and dissemination, yielding difficulties for its control (Araujo *et al*., 2015).Similarly Kumar *et al.*(2022) at Palampur revealed that overall RA, RD and RF was found higher for *Echinochloa colona* followed by *Commelina benghalensis* and *Ageratum conyzoides* in maize.

The density of different weed species during *kharif* 2019 has been presented in Table 7. During summer/ rainy season (2019), *Echinochloa colona* was the most densely populated weed species in maize crop followed by *Cyperus sp., Commelina benghalensis, Polygonum alatum* and *Gallinsoga parviflora*. *Echinochloa colona* had maximum density in mulch (T_4), RSSB + mulch (T_6) and hoeing (T_1). Intensive cropping (T_9), RSSB + mulch (T_6), SSB + hoeing (T_2) and RSSB + hoeing (T_3) showed the maximum density of *Cyperus sp.* whereas, *Polygonum alatum* was having highest density in RSSB + mulch (T_6), RSSB + hoeing (T_3) and SSB + mulch (T_5) treatments. *Galinsoga parviflora* was most densely present in chemical check (T_{10}) treatment. *Alternanthera philoxeroides, Eleusine indica* and *Euphorbia geniculata* had the lowest density amongst all the weeds. Maize grown on soil covered with *Lantana* mulch caused a greater suppressive effect on the other weeds at flowering stage, but it was not efficient in the suppression of Cyperus rotundus L., compared to the manual removal by hoeing. This result may be related to the decomposition of the lantana straw. The other spontaneous plants were affected by the maize shading at later stages of growth and led to weed suppression.

The data on frequency of weed species found growing in maize have been given in Table 8. *Commelina beghalensis* and *Polygonum alatum* were the most frequently occurring weeds in maize. *Commelina benghalensis* was most frequently occurring weed in all treatments except SSB + mulch (T_5) treatment. *Polygonum alatum* was second most frequently occurring weed in mulch (T_4), RSSB + intercropping (T_7) and intensive cropping (T_9). According to Dias *et al*. (2010), *C. benghalensis* is a competitive weed and may cause yield losses in associated crop. Difficulties in its control are associated with its forms of propagation, both by seeds produced by aerial and underground parts and by vegetative parts of stems.

Total weed count (No. m^{-2})

From Fig. 2, it is clearly evident that total weed count increased upto 60 DAS and then showed a decreasing trend afterwards. With respect to reduction in species-wise weed count of almost all species, all the weed control treatments resulted in reduction in total weed count. However, different weed control treatments did not significantly influence the total weed count. Akhtar *et al*. (2015) and Chopra and Angiras (2008) has reported a decrease in weed population after 60 DAS.

Importance value index (IVI)

A perusal of data revealed that *Echinochloa colona* was the most important weed amongst all weeds in mulch (T_4), RSSB + mulch (T_6) and chemical check (T_{10}). It was second in importance in hoeing (T_1), RSSB + hoeing (T_3) and intercropping (T_7). *Cyperus* sp (*C. esculentus* and *C. iria*) was the most important weed after *Echinochloa colona* amongst all weeds in hoeing (T_1), SSB + hoeing (T_2), RSSB + hoeing (T_3), intercropping (T_7) and intensive cropping (T_9). *Commelina benghalensis* was the most important having highest IVI value in crop rotation (T_8). *Galinsoga parviflora* was third most important weed in hoeing (T_1). *Digitaria sanguinalis* was most important weed in crop rotation (T_8). Overall, *Echinochloa colona* was having highest IVI value followed by *Cyperus* sp, *Commelina banghalensis*, *Polygonum alatum*, *Galinsoga parviflora*, *Digitaria sanguinalis* and *Phasalis minima*. Kumar *et al.*(2022) also found that maximum averaged IVI among all the treatments was found for *Echinochloa colona* (55.9%) followed by *Commelina benghalensis* in maize crop. Rana *et al.*(2019) also reported that *Ageratum conyzoides*, *Echinochloa colona* and *Commelina benghalensis* were the major weeds inhabiting the maize field during a survey in 2008 and 2018 in the North-Western Himalayan Region. Pala *et al.*(2020) reported that change in IVI values might be due to climatic changes, soil disturbances during tillage and weed management factors.

Diversity indices (*kharif*)

A total of 13 weed species were found growing in maize under different weed control treatments. Weeds such as *Aeschynomene indica, Commelina benghalensis*, *Cyperus* sp., *Digitaria sanguinalis*, *Echinochloa colona, Euphorbia geniculata*, *Ipomoea*, *Galinsoga parviflora*, *Physalis minima* and *Polygonum alatum* were present at all the times of observation. *Alternanthera philoxeriodes* was observed only during the month of July i.e. 60 DAS and thereafter was absent. In 'chemical control' 11 species in maize were found growing. Eight to eleven weed species were common in 'chemical control' and other weed control treatments in maize. In maize, 0 to 1 weed species was found different from 'chemical control'. Table 10 clearly indicates that with changes in cultural weed management practice, variation in infestation of weed flora occurred. When we try to control/eradicate/limit one species, another species find its way to invade the agro-ecosystem, indicating that successful weed control is a never ending process rather it's a process requiring continuous efforts and requires meticulous care in order to control weeds at critical period of crop weed competition.

Shannon Weiner index was highest for the RSSB + hoeing treatment (T_3) followed by SSB + hoeing (T_2), intercropping (T_7) and chemical check (T_{10}). It was lowest under RSSB + mulch (T_6) followed by hoeing treatment (T_1). In the plots where Stale Seedbed and Raised Stale Seedbed treatments were applied (T_2 and T_3), lesser flush of weeds arrived during 30 DAS but as there were more frequent rains, new flushes of weeds emerged more vigorously. Treatments with mulch provided weed control during initial 30 DAS but later this positive influence weakened but remained for the entire vegetative period. With the onset of monsoon, *Lantana camara* got decomposed and provided organic matter to the soil which was even utilized by weeds and their biomass increased and was not efficient in the suppression of weeds. These circumstances caused the decline of the suppression, which increased the emergence and growth of the weeds. The same fact might have occurred in the present study.

Maize equivalent yield

Intensive cropping where short duration crop of buckwheat was grown in the summer resulted in comparable maize equivalent yield as the chemical check in the *rabi* season. However, RSSB+hoeing, intercropping, RSSB+ mulch and SSB + hoeing were equally good as the chemical check treatment. Similarly the additional crop of mustard after the harvest of maize in the autumn resulted in significantly higher maize equivalent yield under intensive cropping in the *kharif* season. Chemical check was the next superior treatment and RSSB + hoeing and intercropping treatments were at par to it. Intensive cropping because of more yield from additional crops resulted in 10.4% higher overall system's maize cob equivalent yield than the chemical check. RSSB + hoeing and intercropping resulted in comparable yields as chemical check. The other treatments owing to lower crop yields were having low maize green cob equivalent yield as compared to the chemical check. The superior performance of raised stale seed bed in comparison to others may be owed to the radiational heating of bed that led to rapid heating which discouraged weed seed germination and thus lower weed count. Similar findings were reported in peas (Tehria *et al*., 2015) and wheat (Kumar *et al*., 2015) under similar ecological situations.

CONCLUSION

In the organically managed maize-pea production there was greater weeds floristic diversity with invasion of 22 species in *rabi* and 13 in *kharif* during 2018-19. Amongst the evaluated weeds, *Stellaria media*, *Phalaris minor* in pea and *Commelina benghalensis, Echinochloa colona* in maize were the weeds of highest importance competing with the main crops. They were dynamic in nature and their distribution, density and abundance greatly varied due to weed management practices. However, recurrence of same weed species over the past years proved that those weed species were adapted to the edapho-climatic conditions of the area and developed seed banks over the past years. By adopting organic weed management, one can reduce the herbicide application and improve the production system. Changes in diversity of weeds reinforces the importance of carrying out a phytosociological survey to analyze the weed population dynamics and establish adequate weed management strategies in future as well.

Future thrust

Phytosociological studies are of paramount importance, enabling the monitoring of the entry and exit of plant species from a crop production system .The study directly assists in the choice of control strategies for efficient weed management that are not only economically feasible but maintain sustainability as well. Long term trials on weed management for a minimum of atleast 7-8 years are required to interfere with the weed life cycles, especially in rainfed conditions of mid hills.

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