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WEED CONTROL MEASURES FOR CONTROLLING THE DENSITY OF CANADA THISTLE (*CIRSIUM ARVENSE* (L.) SCOP. IN WHEAT (*TRITICUM AESTIVUM* L.)

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Abstract

Canada thistle [*Cirsium arvense* (L.) Scop.] is a major weed in semi-arid areas of Punjab, Pakistan. studies were conducted during 2010-11 and 2011-12 at University Research Farm, Chakwal road, Rawalpindi to study Canada thistle control and density dynamics in wheat grown under contrasting environments and diverse cultural, mechanical and chemical thistle control measures. Experiments were carried out in randomized complete block design with four replications. Canada thistle density was monitored at five stages during wheat growing season. The results revealed during wet winter season, Canada thistle was effectively controlled (90-97%) when dry-season tillage was integrated with fertilizer placement in a strip along crop row and with single application of full dose of clopyralid. The drier winter season witnessed significant thistle control (91%) with half dose of clopyralid when integrated with dry-season tillage, fertilizer placement followed by inter-row cultivation and remained at par with experimental treatment where full dose of clopyralid was applied. The thistle dynamics data showed that higher thistle re-sprouting during wetter environment decreased efficiency of thistle control in cultural and mechanical control measures applied either in integrated or sole fashion.

Key words: *Cirsium arvense* density, Weed control measures, Wheat.

Introduction

Population is growing at a high speed in Pakistan, and a majority of the population is involved directly or indirectly with agriculture to generate their income (Butt *et al.,* 2010; Ali *et al*., 2016; Abbas *et al.,* 2017). This sector is playing a key role in reducing poverty and acts as a source of growth in the countries where it is a main source of livelihood for the poor providing the basic necessities of life such as shelter, clothing and food (Ishaq & Memon, 2016; Qasim *et al.,* 2016; Lakho *et al*., 2017). It provides raw materials to industries and also serves as a market of its product thereby it contributes a lot to the national income (Begum & Yasmeen, 2011; Khan *et al*., 2016; Anjum *et al*., 2016). It has several linkages with other non-farm rural activities and hence results in employment generation and income earning opportunities (Anjum *et al.,* 2016; Rozina *et al*., 2017).

Wheat is the staple food crop for more than one third of the world population, used mainly as a human feed (Mehmood *et al*., 2016; Channa *et al*., 2017; Khan *et al*., 2017). It is also a major cereal crop of Pakistan and its share is 3.4% to GDP and 13.8% to agriculture value addition (Adeel *et al*., 2017; Javaid *et al*., 2017). But its yield potential is low due to weeds competition (Chhokar *et al*., 2007; Jan *et al*., 2017). Canada thistle [*Cirsium arvense* (L.) Scop.] is a broad-leaved, invasive, perennial herbaceous plant of Asteraceae family (Tiley, 2010; Sciegienka *et al.,* 2011) and is one of the worst weeds in arable production systems worldwide (McClay *et al*., 2002). Canada thistle is a dominant weed of semi-arid areas of Punjab, Pakistan (Nasir & Sultan, 2003). Farmers are worried about increasing Canada thistle infestations in wheat and have reported substantial decrease in crop yield (Anser *et al*., 2010). Previously it has been reported that other thistles like milk thistle (*Silybum marianum* Gaertn. resulted in losses of grain yield in wheat and the competitive ability of this thistle was season and density dependent (Khan & Marwat, 2006; Marwat & Khan, 2007).

Canada thistle has been reported to cause extreme yield losses (Darwent *et al*., 2006) through competition for light, nutrients and moisture (Jacob *et al.*, 2006; Anser *et al.,* 2010) even at lower thistle infestation level (6-20 shoots m^{-2}). Higher thistle infestations (40 shoots m^{-2}) have been found in rainfed wheat of Pothwar region. Such infestation level even does not allow farmers to harvest the crop and thus sometime fields are left un-harvested because of refusal of local labour to perform harvesting operation at normal wages. Moreover, Canada thistle may become even more troublesome and difficult to control in the looming climate change scenario as its growth and resistance to herbicides have been found to increase with increasing levels of CO_2 (Ziska *et al*., 2004). The existing Canada thistle control measures i.e. hand weeding, contact herbicide application (bromoxynil + MCPA), and leaving the land tilled fallow for more than two years, were either highly labour intensive or expensive and they did not provide full season control of this weed (Anser *et al*., 2010). The farmers need alternate strategy to reduce Canada thistle infestation and minimize yield losses in wheat. Because wheat is a major cereal and contributes a key share to livelihood of poor farmers and is grown on 80% of the cultivated lands in semi-arid regions of Punjab, Pakistan (Razzaq *et al*., 2002).

Controlling Canada thistle is not an easy task on account of its deep root system, underground creeping roots and its ability to re-grow. This may be achieved through good crop husbandry, fertilizer placement techniques, choice of competitive crop or cultivar, interference in life cycle of weed through soil manipulation (Kurstjens, 2007) and exposing its roots to high temperature (>30ºC) during dry season (Mamolos & Kalburtji, 2001). Sole reliance on ecological control methods often did not give complete control of the weeds, unless integrating with some weed killing techniques (Kirkland & Beckie, 1998; Pollak & Bailey, 2001; Defra, 2008).

Canada thistle control may vary with change in climatic conditions. Scarce data are available on thistle control in semi-arid areas with sub-tropical climate. Moreover, thistle control is often monitored few weeks after application of control measures without observing weed behavior throughout crop growth season as it has the ability to re-grow. Therefore, this study was designed to assess various control measures on thistle density from initiation to wheat harvest. As Canada thistle density might be helpful in pointing out strengths and weaknesses of control measures at specific stages during crop growth period. During this study, it was also hypothesized that integration of cultural, mechanical and chemical thistle management strategies would be more effective than that of single method of control to reduce Canada thistle infestation.

Materials and Methods

Experimental sites and thistle control measures: Three independent studies were conducted at two sites at University Research Farm, Chakwal Road, Gujjar Khan (Latitude = 33.12º N, Longitude 73.02º E, Altitude: 606 m) during 2010 to 2012. Before the start of these experiments, the research sites remained under conventional wheat cultivation continuously for at least five years. Before the start of the experimentation, a field appraisal was done to identify a few sites with relatively uniform infestation of Canada thistle. The selected sites represented “worst-case” situation, where thistle density was relatively greater than that found in wheat fields in the region and it was also ensured to have uniform density in the research sites. Various weed control methods (WCM) were followed during this study to control the density of Canada thistle (Table 1).

Table 1. Various weed control methods (WCM) used in this study to control the density of Canada thistle.

Treatment name	Treatment detail
WCM_1	Un-weeded control
WCM_2	Wheat seed soaking
WCM_3	Fertilizer placement (FP)
WCM_4	Dry season tillage (DST)
WCM_5	DST + FP
WCM_6	Hand weeding (HW)
WCM_7	DST + HW
WCM_8	DST + Inter-row cultivation (IRC)
WCM_9	DST+ FP + IRC
WCM_{10}	Clopyralid herbicide @ 620 ml ha^{-1}
WCM_{11}	DST + Clopyralid herbicide
WCM_{12}	DST + FP + Clopyralid herbicide
WCM_{13}	DST +FP+IRC + Clopyralid @ 310 ml ha^{-1} [1/2 dose]

Weed control measure ‘WCM_{13}’ was evaluated only at site-II during 2011-12, based on the results of first year experimentation. The dry season tillage was carried out during the fallow period (mid May) when weather was hot and dry to ensure exposure of thistle creeping roots to the heat of sun (40°C). This involved shallow stubble tillage (once with cultivator) after wheat harvest followed by deep tillage once with mouldboard plough. Afterwards, five shallow cultivations were done with cultivator till wheat seedbed preparation. Fertilizer placement was done at the time of wheat sowing using seed-cum fertilizer drill to place fertilizer 5 cm deep. Hand weeding as farmers practice was done repeatedly 3-4 times at three weeks interval with hand hoe. Inter-row cultivation was mechanically done 40 days after wheat sowing. The herbicide “Clean field 30 SL” (Clopyralid) was applied as post-emergence (60 DAS) at about 80% emergence of Canada thistle. Before application, the sprayer was calibrated to deliver the required spray volume (250 L ha^{-1}). Clopyralid (3, 6-dichloro-2-pyridinecarboxylic acid) was applied with a Knapsack hand sprayer equipped with T-Jet nozzle.

Cultural practices: Each experimental plot consisted of sixteen 6 m rows, spaced 0.25 m apart (4 m & 6 m in dimension). Establishment of 3.5 m discard in between replications and experimental units facilitated mechanical inter-row hoeing with tractor in respective plots. A competitive wheat cultivar ‘Chakwal-50’ was used as test variety for rainfed areas of Pothwar with seed rate of 100 kg ha^{-1}. The fertilizer; urea, diammonium phosphate and potassium sulphate @ 90-60-60 kg ha^{-1} was applied as basal dose. Wheat sowing was done using tractor drawn seed-cum fertilizer drill. During wheat growing season, unwanted weeds were removed from the experimental plots from time to time to avoid extra competition. During 2nd year (dry year), the experiment was conducted on a new site to avoid residual variation in thistle infestation. However, the experimental treatments were also applied on previous year site to extract data regarding cumulative effect of treatment application.

Weed density: Canada thistle density was recorded periodically at six stages during wheat growing season at 35, 60, 85, 110 and 130 days after wheat sowing and at harvest to determine thistle control and density dynamics both during wetter and drier environments during winter seasons. Thistle density was recorded from two 50 x 50 cm representative quadrats from each experimental unit at respective stage. The representative quadrats were marked 30 days after sowing of wheat for periodic data collection. Individual thistle shoots were counted to determine average shoot density per m^2.

Statistical analysis: The experiments were conducted in Randomized Complete Block Design (RCBD) with four replications. The data were subjected to analysis of variance technique. F-statistic was based on residual mean square error. The DMR at 5% level of probability was used for comparison of treatment means (Steel *et al*., 1997).

Results and Discussion

Summer seasons: Dry season tillage was done during preceding summer seasons during 2010 and 2011 to expose Canada thistle roots to hot and dry weather. After carrying out dry-season tillage, hot and dry weather prevailed (Fig. 1) for 42 days during 1st year and 45 days during 2nd year. Monthly maximum temperature was recorded as 45.0°C & 43.2°C during the same period in 1st and 2nd year, respectively. During these days, no major rainfall was received in 1st year, while 2nd year witnessed only one major rainfall (21 mm) during 4th week of May. It was found that the maximum temperature remained higher than 30°C which was sufficient enough to desiccate exposed Canada thistle creeping roots as reported by Mamolos & Kalburtji (2001).

Winter seasons: Considerable seasonal variability in rainfall (Fig. 2) and temperature (Fig. 3) provided unique opportunity to study environmental effects on thistle dynamics under field conditions. Seasonal rainfall during winter 2010-11 was 191 mm. The particular season can be regarded wet in this respect; while winter season 2011-12 was an exceptionally dry as only 85.6 mm rainfall was received. Both years witnessed rainfall at the time of wheat sowing. Higher rainfall (20 mm) during 2010-11 provided conducive conditions for early thistle growth than year 2011-12 where rainfall was 10 mm. Rains during last week of December (~60 days after wheat sowing provided favorable environment for herbicide activity). During 2011-12, dry weather prevailed from 2nd week of February to wheat maturity which greatly enhanced thistle growth and re-sprouting as compared to 2010-11winter season (Figs. 1-3).

Temperature variations are depicted in Fig. 3. The prevalence of temperatures close to freezing point for 12-17 days during December-January might have affected Canada thistle growth as it was sensitive to frost (Hakansson, 2003). The existence of wide differences in environmental conditions between study years led to present research results separately for different years rather than pooled results.

Soil characteristics of study sites: The experiments were conducted on two research sites. The physico-chemical analysis of soil (0−15 cm) revealed that the soil was sandy clay loam in texture at site-1, while at site-II, textural class was sandy loam. The electric conductivity (0.25−0.43 dSm^{-1}) shows that both soils were free of salinity problem but poor in organic matter (0.22−0.37%) and available phosphorus (2.11−2.71 mg kg^{-1}). The soil reaction was alkaline with pH around 8 at all the sites.

Canada thistle density 35 days after wheat sowing: Data about Canada thistle density by various experimental treatments recorded 35 days after sowing (DAS) are presented in Fig. 4. The data only represent effect of sole dry season tillage (DST) or its integration with fertilizer placement (FP) on thistle emergence because neither the hand weeding was carried out nor herbicide/ Inter-row tillage was applied at this stage.

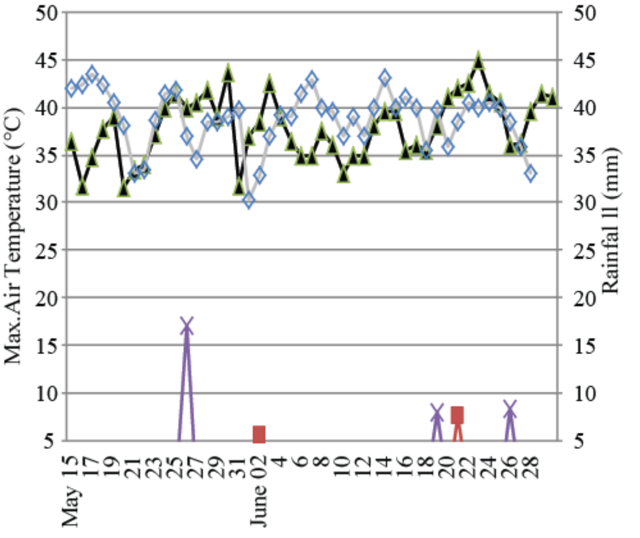

Fig. 1. Maximum air temperatures and rainfall after carrying out dry season tillage [May 15].

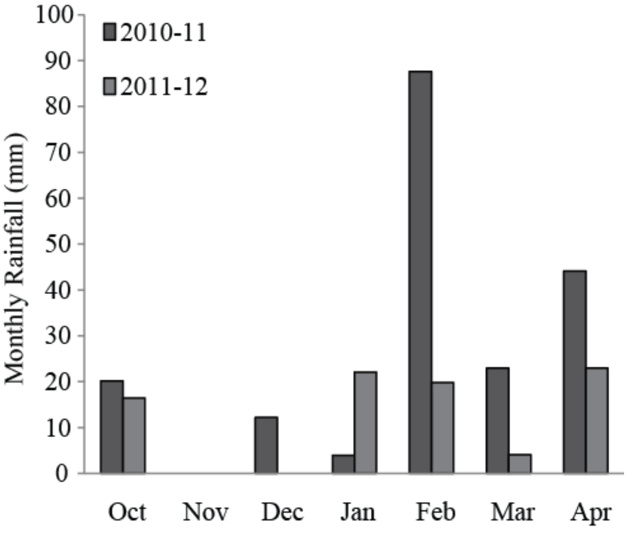

Fig. 2. Monthly rainfall during winter seasons 2010-11 and 2011-12.

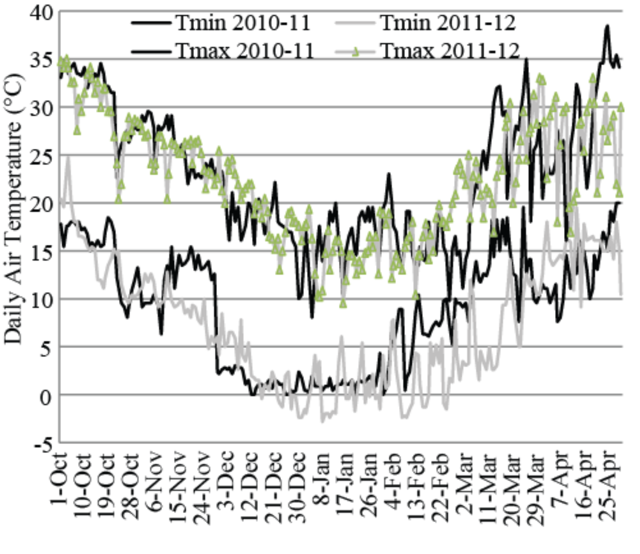

Fig. 3. Minimum and maximum air temperatures (°C) during winter seasons.

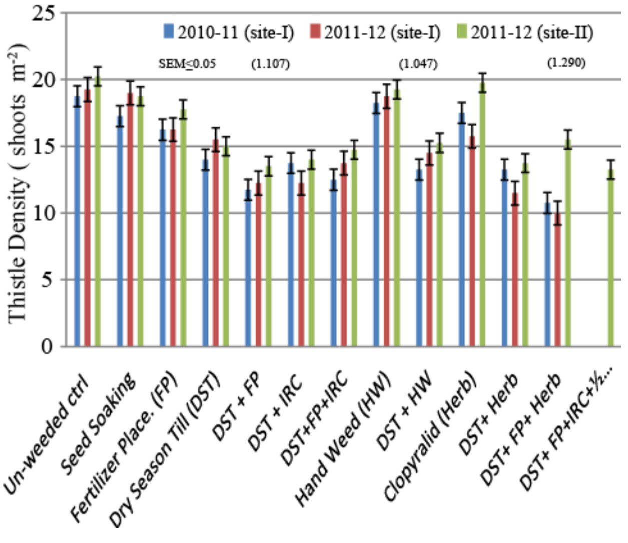

Fig. 4. Canada thistle density under different weed control measures 35 DAS of wheat.

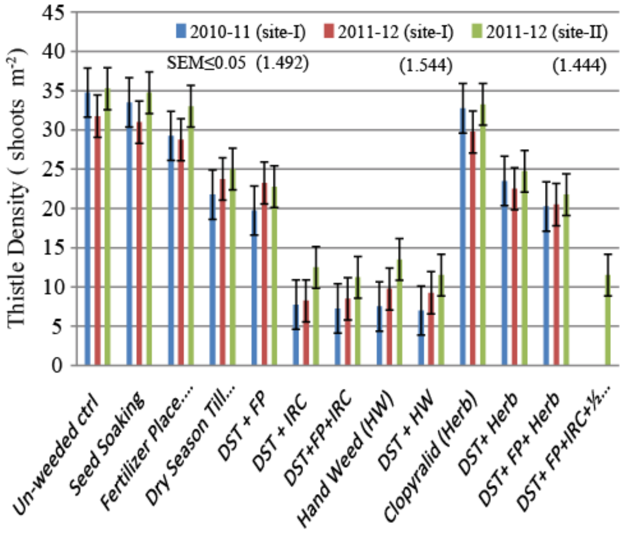

Fig. 5. Canada thistle density under different weed control measures 60 DAS of wheat.

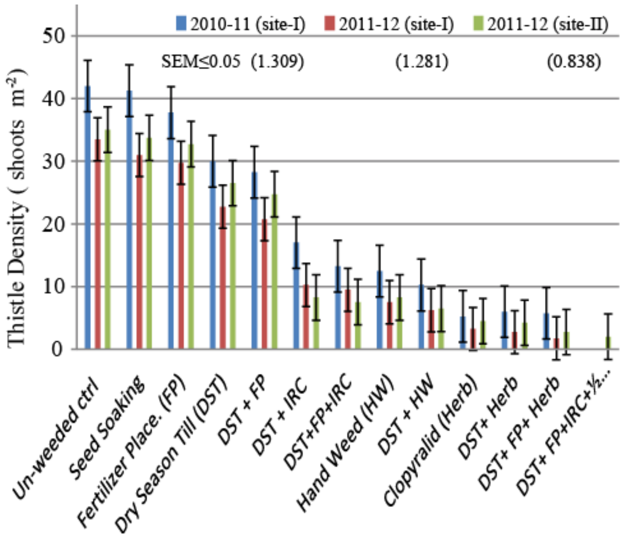

Fig. 6. Canada thistle density under different weed control measures 85 DAS of wheat.

The effect of dry season tillage (DST) on thistle density was significantly prominent during both the study years. Significantly, lower thistle emergence (25.3−29.3 shoots m^{-2}) was recorded in DST plots as compared to un-weeded control during 2010-11. The extent of decline in thistle emergence was 18.4−39.5% at site-I, whereas 24.7 to 32.1% at site-II during 2011-12. During 2nd year, site- I represented cumulative effects of treatment for two years as the site received weed control measures continuously for two years. The integration of DST with FP further improved suppressive effect on thistle emergence. The additive effect of FP on impeding thistle emergence in DST+FP experimental units was relatively higher during 2010-11 (8−13%), and lower during 2011-12 (6-9% at site-I and around 2% at site-II) over DST. During 2010-11, possible reason for higher integrated effect may be attributed to higher water availability in the form of rainfall which might have led to better nutrient use, while the extent of effect was reduced during 2nd year on account of low rainfall at the time of wheat sowing. During 2nd year (site-I), lower thistle emergence was recorded in plots that were treated with clopyralid during previous year. This could be attributed to the residual effect of clopyralid (Fay & Davis, 1985).

The significant reduction in thistle emergence in plots receiving DST can be mainly attributed to desiccation of thistle roots on account of continuous exposure to high temperature (> 30ºC; Fig. 1) during preceding summer seasons. The exposure of Canada thistle roots to high temperatures during dry weather conditions, after dry season tillage might have resulted in better root killing as evident from thistle emergence data at this stage. These findings are in agreement with Mamolos & Kalburtji (2001) who reported thistle roots destruction because of high temperature stress (> 30ºC). Sciegienka *et al*. (2011) reported that thistle emergence was mainly determined by depth of root burial with the lowest thistle emergence from 20 cm and the highest from 10 cm soil depth. Highest mortality of root fragments was observed which received exposure during dry period. Hakansson (2003) reported disruption of storage root functioning due to exposure to higher temperatures as thistle is a C_3 plant species. Hamdoun (1972) reported that artificial drying of thistle root cutting to lower water contents (≤20%) impeded thistle root growth which led to production of lesser thistle shoots subsequently. Moreover, lower thistle emergence at this initial stage in plots where fertilizer was placed (FP) along seed row may be attributed to non-availability of nitrogen to thistle propagules for emergence between crop rows as more availability of nitrogen to thistle plants in broadcast application was found to increase thistle density (Nadeau and Van Born, 1990). Hamdoun (1970) also observed higher thistle emergence when more nitrogen was available.

Canada thistle density 60 days after wheat sowing: Maximum thistle density was recorded at this stage. The data represented the real effect of mechanical thistle control measures (Hand weeding and inter-row cultivation) in spring wheat in addition to carryover effects of DST and FP on thistle density (Fig. 5). In general, higher thistle infestation was recorded at this stage than at 35 DAS of wheat. This might be attributed to delayed emergence of thistle plants from great soil depths as noticed by Dock-Gustavsson (1997) by studying thistle emergence from different depths. Un-weeded check was observed to have the highest thistle density of 34.75% shoots m^{-2} (during 2010-11), 31.75% shoots m^{-2} (during 2011-12 at site-I) & 35.25% shoots m^{-2} (during 2011-12 at site-II) (Fig. 5). Thistle plants were at rosette stage of their growth in all experimental plots.

The effect of various weed control measures on thistle density was significantly variable. Hand weeding resulted in 61−78% reduction in thistle density over control with better response during study period 2010-11. Integration of DST with HW further produced thistle density reduction (67−80%) as compared to un-weeded check. The effect of FP on thistle density management ranged from 6.4% to 15.8% with higher effect during 2010-11 than 2011-12 on account of better rainwater availability during 1st year. Dry season tillage (DST) effect on thistle density control was significantly visible. Canada thistle density was around 35% lower in DST plots during 2010-11 but 28% during 2011-12 over un-weeded check. The better thistle reduction during 2010-11 may be attributed to relatively more dry conditions during preceding summer causing more thistle root desiccation. Integration of DST with FP resulted in 5-10% higher reduction of thistle density over sole DST with poor response during dry year (2011-12).

Inter-row cultivation brought significant reduction in thistle density over un-weeded check when it was integrated with DST. Integrated effect of DST and IRC was more pronounced and significantly higher over sole DST as thistle control measure. The reduction in thistle density increased from 35% to 77% over control during 2010-11. At this stage the trend in thistle reduction due to integration of DST with IRC was almost similar during 2nd year. Integration of DST with IRC and FP slightly improved (2−3%) the integrated effect of treatments on thistle density reduction over DST+IRC treatments. The possible reason for enhanced effect of IRC and HW on thistle reduction might be due to the fact after carrying out IRC, no rainfall was received for 21 days during 2010-11 and 26 days during 2011-12, which prevented thistle re-sprouting during this dry period (Figs. 4-5).

Canada thistle 85 days after wheat sowing: The data pertaining to thistle density 85 days after wheat sowing are shown in Fig. 6. The stage is unique with regard to the effect of all thistle control measures on thistle density during both study years. Adequate rainfall on last day of December 2010 promoted thistle emergence by which thistle density increased to 42 shoots m^{-2} in un-weeded control plots. However, delayed rainfall during 2011-12 did not favor more thistle emergence to that extent; therefore, it stood at around 34 shoots m^{-2} in un-weeded plots. However, it was at par with seed soaking treatment with respect to Canada thistle density. Higher thistle density during 2010-11 could be attributed to root-bud dormancy release because of prevalence of higher water content (higher rainfall) as reported by Hunter *et al*. (1985) in Canada thistle and by Hsiao & Mclntyre (1984) in milk weed. However, lower density during 2011-12 may be attributed to the occurrence of drought which might be the result of reduced density of adventitious root buds of thistle as reported by Donald & Nalewaja (1990).

The effect of FP on thistle density reduction remained 10% during 2010-11 and 6−11% during 2011-12 over control. A 2nd hand weeding during 9 weeks after sowing prevented thistle re-sprouting and helped to improve thistle control (70−80% over un-weeded check). The repeated thistle shoot cutting probably have caused continuous depletion of thistle root reserves as reported by Bostrom & Fogelfors (1999) and Hakansson (2003). Application of clopyralid during 60−65 days after wheat sowing resulted in significant weed kill. One application of clopyralid herbicide resulted in 86% weed kill during 2010-11 and 87−95% weed kill during 2011-12 over un-weeded check owing to smaller size of thistle plants during 2011-12 which resulted early kill of the weed. The results are supported by the findings of Fay and Davis (1985), who found 80−85% reduction in thistle stands with the application of clopyralid. The improved efficiency of clopyralid in integrated thistle control system DST+FP+Clopyralid is in agreement with the findings of other workers. Grekul & Bork (2007) reported enhanced control of thistle when herbicide application was integrated with crop fertilization during spring.

Canada thistle re-sprouting in inter-row cultivation (IRC) treatments slightly decreased its efficiency (12-17%) towards thistle control during 2010-11 on account of higher rainfall. Moreover, IRC was found not to control intra-row weeds. The weed behavior under DST+IRC and DST+FP+IRC thistle control measures led to evaluate its efficiency in integration with half dose of clopyralid during next year. However, no or little re-sprouting was observed during 2011-12. The reason might be the occurrence of drought accompanied by prevalence of more frosty nights during 2nd year. Minimum temperature remained below freezing point for 17 nights during Dec-Jan which might have invited better thistle kill and prevented re-sprouting. The observations are in line with the findings of Hakansson (2003) who reported thistle sensitivity (mainly aerial parts) to frost resulting in plant death during winter. Moreover, great reduction in thistle establishment from its roots was observed by him under drought. The integration of half dose of clopyralid with DST+FP+IRC gave excellent thistle kill (94%) over un-weeded check. The possible reason could be the control of intra-row weed kill by herbicide which generally escapes any mechanical or cultural control practice as reported by Donald (1990).

Canada thistle density 130 days after wheat sowing: Various mechanical and chemical thistle control measures applied either sole or in integrated fashion behaved differently regarding in magnitude of Canada thistle control at both study sites during relatively wet (2010-11) and dry (2011-12) years. The data (Fig. 7) among certain sole thistle measures (Seed soaking and FP) proved ineffective in controlling Canada thistle, whereas others (HW and herb) showed their superiority over un-weeded control. Maximum infestation of 32−38 shoots m^{-2} was observed in un-weeded control. The behavior of seed soaking treatment, with only 3−6% thistle reduction (over control), was not much remarkable from un-weeded check. The effect of sole DST on thistle reduction was also not very impressive i.e., 18−31% over un-weeded check.

Among non-chemical thistle control measures, HW and its integration with DST, proved very effective in controlling Canada thistle with 87−89% reduction over control at site-I during 2010-11 while 80% at site-II during 2011-12. Integration of DST+FP+IRC controlled thistle up to 66% against 46% and 63% thistle reduction in DST+IRC over un-weeded check during 2010-11 and 2011-12, respectively. The Canada thistle control under non-chemical thistle control practices was relatively better during dry year (2011-12) as compared to relatively wet year (2010-11) on account of little re-sprouting of thistle during dry year and wheat growing season. Integration of DST with FP without any subsequent thistle control measure showed 18-31% thistle control over un-weeded check.

Canada thistle control under chemical weed control practices either sole or integrated with cultural and mechanical measures resulted in significantly higher thistle control during both study years. Single clopyralid application resulted in 88-92 percent thistle reduction over control. Clopyralid integration with DST and FP improved thistle control efficiency in the range of 3−5% further. The best performance was showed by integration of DST, FP, IRC and half dose of clopyralid. This reduced thistle density from 32 shoots m^{-2} (un-weeded check) to 2.75 shoots m^{-2}. This integrated treatment technically seems more appropriate as it helped to reduce herbicide dose for controlling Canada thistle with efficiency similar to treatments where full dose of clopyralid applied. The findings are supported by work of Zhang *et al*. (2000) who indicated that registered dose of herbicides is recommended for wide range of environments and growth stages of weeds to achieve effective weed control. However, great potential of herbicide dose reduction exists in certain cases (Blackshaw *et al*., 2006).

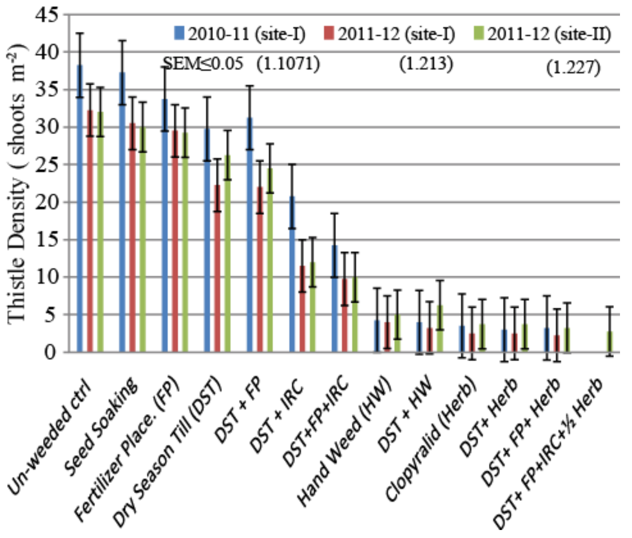

Fig. 7. Canada thistle density under different weed control measures 130 DAS of wheat.

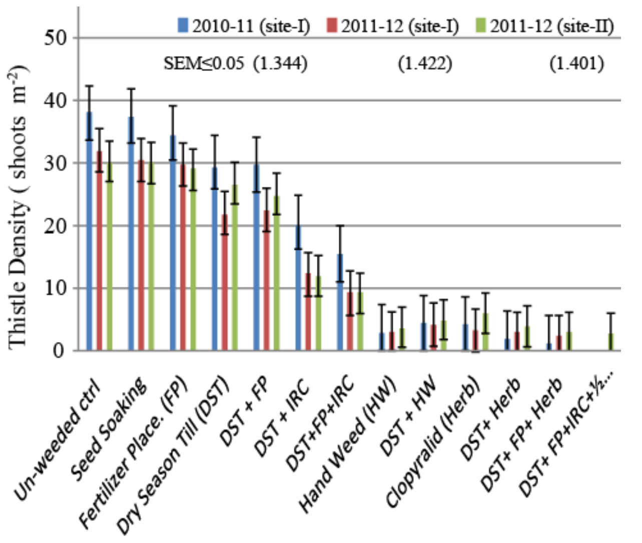

Fig. 8. Canada thistle density under different weed control measures at wheat harvest.

Canada thistle density at wheat harvest: The ultimate technical suitability of any weed control measure is judged by its potential in carrying over its effects till harvest with higher efficiency. Thistle density data at wheat harvest (Fig. 8) showed that the best integrated thistle control strategy was integration of DST and FP with single application of clopyralid herbicide. This integrated practice exhibited 90−97% thistle control at both study sites during 2010-11 and 2011-12 in comparison to un-weeded control where final thistle density was 38 shoots m^{-2} during relatively wet year (2010-11) and around 31 shoots m^{-2} during 2011-12. This was followed by integration of DST, FP and IRC with half dose of clopyralid with 91% thistle reduction over un-weeded check. Among other weed control measures, thistle reduction in hand weeded plots was almost similar to clopyralid treated plots. The weed reduction in repeated HW plots ranged from 85−90% whereas in clopyralid treated plots showed around 90% thistle control across sites and years. Our results of frequent cutting by HW were in line with findings of Bostrom & Fogelfors (1999) and Hakansson (2003) who reported similar findings and argued that it might have depleted assimilates in thistle continuously through frequent cutting. The highly significant effects of clopyralid on thistle density reduction are supported by findings of Fay & Davis (1985), Curtis & Haagsma (1986) and Donald & Prato (1992), who observed 80−96% thistle control with in-crop clopyralid application in wheat/cereals. The effectiveness of herbicide may be attributed to better rainwater availability in soil profile at the time of its application which could have facilitated its translocation as reported by Tworkoski *et al*. (1998).

Fertilizer placement which had initially affected density but at later stages it was found to have non-significant effect on thistle density as observed by Melander *et al*. (2003). They reported that FP had little or no effect in controlling perennial weeds in winter barley. Integration of DST, FP and IRC resulted in 61−70% thistle density reduction as compared to un-weeded check. Thistle control would have been more remarkable if delayed emergence in DST and its re-sprouting or in IRC would not have occurred. IRC was practiced only once (December), therefore, it checked and not completely controlled thistle. The results are in line with findings of Amor & Harris

(1977) who reported ineffectiveness of in-frequent cutting. Delayed emergence in DST also decreased its thistle control efficiency which was reduced to 12−31% over un-weeded control from initial 25−38%. Prevalence of drought during 2nd year at site-1 affected thistle growth and masked the cumulative effect of weed control measures as were observed by Grekul & Bork (2007).

The results of satisfactory thistle control under DST+FP+IRC integrated with half dose of clopyralid are in agreement to the findings of Zhang *et al*. (2000) and Barros *et al*. (2005), who reported that application of lower rates of herbicides have often resulted in adequate weed control (over general recommended doses) when combined with mechanical control practice. The results are also in line with findings of other scientists (Salonen, 1992; Zhang *et al*., 2000). They reported that integration of crop management practices with herbicide use at reduced rates was found to give successful weed reduction (77−95% over un-weeded control). The findings are also supported by work of Pollak & Bailey (2001) and Defra (2008) about effectiveness of integrated control measures. They demonstrated that integrated approaches involving cultural and chemical methods was found effective in all cropping systems.

The cluster trees prepared on the basis of Canada thistle density at wheat harvest revealed greater effect of environmental changes on thistle control. During a wet year, the highest thistle control was achieved by weed control measures involving one foliar application of clopyralid at 60 DAS (Fig. 9) which remained at par with hand weeding. Thistle suppression in all other control measures (cultural & mechanical) was less effective. However, during a dry year (Fig. 10), half dose of clopyralid gave similar thistle control when it was integrated with cultural (fertilizer placement) and mechanical thistle control measures such as DST and IRC. The results confirm our hypothesis that integration of weed control measures would give enhanced suppression of the Canada thistle in comparison to sole use of any practice in semi-arid areas with sub-tropical climate (Figs. 8-10).

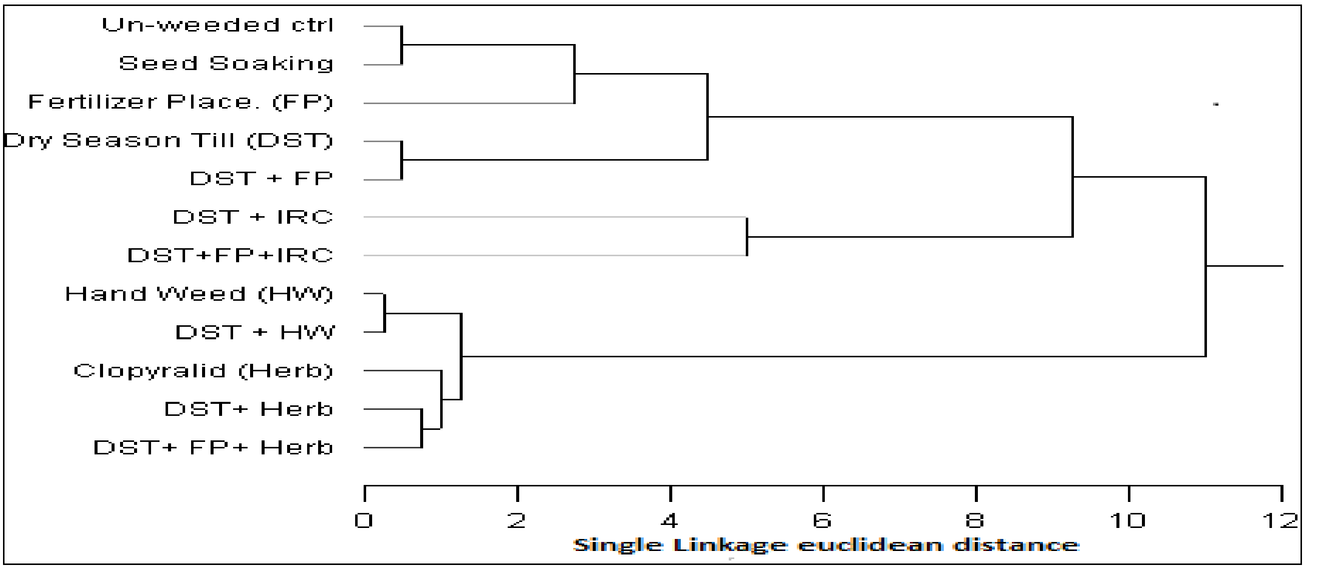

Fig. 9. Cluster tree showing similarity between Canada thistle control measures during wet year (2010-11).

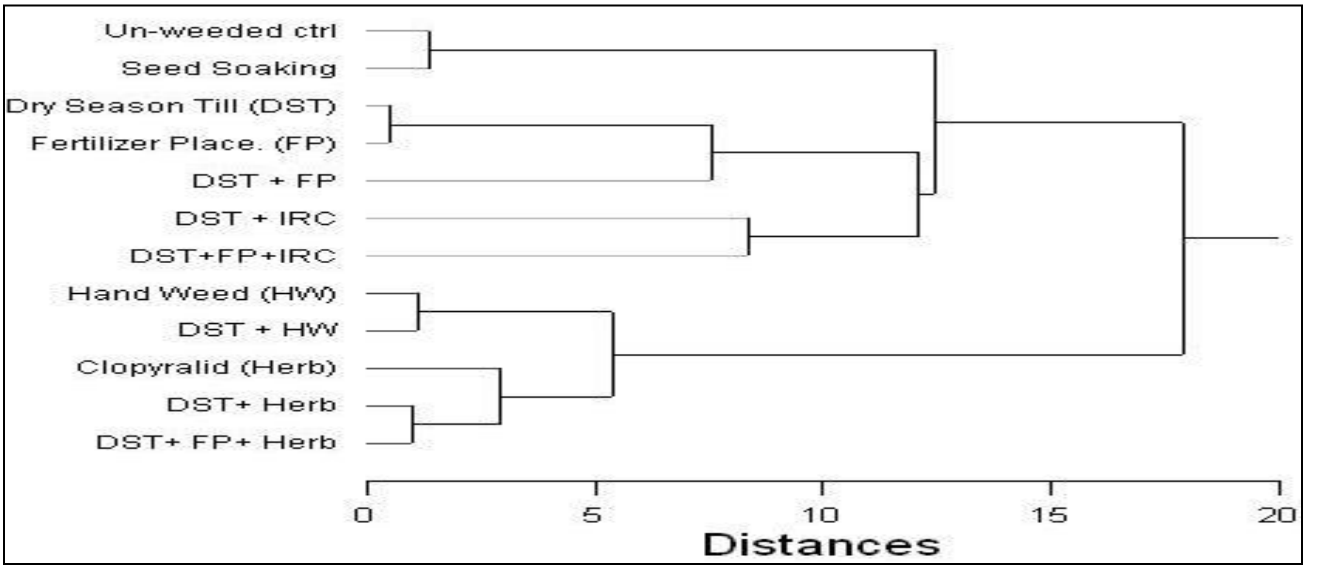

Fig. 10. Cluster tree showing similarity between Canada thistle control measures during dry year (2011- 12).

Conclusion

The results suggest that in the semi-arid areas significant reduction in thistle density can be achieved during wet season, by carrying out dry season tillage during May (after wheat harvest) followed by nitrogenous fertilizer placement with drill at crop sowing time and one foliar application of clopyralid. However, during a drier winter season, effective control was achieved through integration of DST, FP with one mechanical inter-row cultivation 40-45 DAS and clopyralid application at half rate. The results also revealed that the combined effect of various control measures was significantly higher than sole application of various practices.

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