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INTEGRATED APPROACHES FOR WEED SUPPRESSION IN CHICKPEA (*Cicer arietinum*) UNDER RESIDUAL MOISTURE AFTER RICE CROP

*Abordagens Integradas para a Supressão de Plantas Daninhas no Grão-de-Bico (*Cicer arietinum*) sob Umidade Residual após o Cultivo de Arroz*

ABSTRACT - Three-year field studies were undertaken at Agricultural Research Institute, Dera Ismail Khan, Khyber Pakhtunkhwa Province, Pakistan from 2010-11 to 2012-2013 with the aim of assessing the efficacy of different management techniques on weed growth and yield of chickpea under rain-fed conditions on residual moisture of a previous rice crop. Treatments of the experiment consisted of recommended full and half doses of three herbicides, i.e., Stomp 330E, Dual Gold 960EC and Isoproturon 500EW and the plant extract of *Parthenium hysterophorus*. Hand weeding treatment was kept as positive control whereas weedy check was included as negative control treatment. The experiment was laid out in a Completely Randomized Block (CRB) design replicated thrice. Parameters of the investigation were weed density, fresh weed biomass, chickpea growth, biological yield and seed yield. The data revealed that the full dose of Stomp 330E proved superior in terms of weed suppression by giving only 84, 69 and 55 weeds m⁻² as compared to weedy check for the years 2010-11, 2011-12 and 2012-13, respectively. Likewise, the highest plant height and seed yield were also recorded for Stomp 330E (full dose) during the entire study, which was statistically at par with hand weeding. However, there was a reduction in overall chickpea yield during the second and third years of experimentation resulting from lower average rainfall. The extract of *P. hysterophorus* followed Stomp 330E in weed suppression, enhancing plant height as well as biological yield and seed yield. Moreover, the result also shows statistically similar results of the extract of *P. hysterophorus* for all other tested treatments. Based on the findings of the present research, it was found that herbicides and hand weeding showed superior results in terms of all tested parameters. However, both approaches are non-judicious: hand weeding is laborious while herbicides may cause environmental pollution, hence the herbicidal potential of *P. hysterophorus* needs to be encouraged in order to achieve sustainable weed management and high yield in an eco-friendly manner.

Keywords: herbicides, Stomp 330E, parthenium extract, residual moisture, weed control, seed yield.

RESUMO - Estudos de campo foram realizados ao longo de três anos no Instituto de Pesquisas Agrícolas Dera Ismail Khan, província de Khyber Pakhtunkhwa, Paquistão, entre 2010-11 e 2012-2013, com o objetivo de avaliar a eficácia de diferentes técnicas de manejo no crescimento de plantas daninhas e rendimento do grão-de-bico sob sistema de irrigação pela chuva em umidade residual de cultivo prévio de arroz. Os tratamentos do experimento foram compostos de doses totais e meias doses, conforme recomendação do fabricante, de três herbicidas: Stomp

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330E, Dual Gold 960EC e Isoproturon 500EW, além do extrato vegetal de *Parthenium hysterophorus*. O tratamento com capina foi mantido como controle positivo, enquanto o tratamento sem capina foi incluído como controle negativo. O experimento teve delineamento em blocos completamente casualizados com três repetições. Os parâmetros da investigação foram densidade de plantas daninhas, biomassa fresca de plantas daninhas, crescimento de grão-de-bico e rendimento biológico e de sementes. Os dados revelaram que a dose total de Stomp 330E foi superior em termos de supressão de plantas daninhas, com apenas 84, 69 e 55 plantas daninhas m⁻², em comparação com o tratamento sem capina nos períodos de 2010-11, 2011-12 e 2012-13, respectivamente. Da mesma forma, também foram registrados maior altura das plantas e maior rendimento de sementes com o Stomp 330E (dose total) durante toda a duração do estudo – um resultado estatisticamente semelhante ao da capina de plantas daninhas. No entanto, durante o segundo e o terceiro ano do experimento, foi observada redução na produção total de grão-de-bico, proporcional à menor precipitação média. Assim como o Stomp 330E, o extrato de *P. hysterophorus* também suprimiu as plantas daninhas, aumentando a altura das plantas e o rendimento biológico e de sementes do grão-de-bico. Além disso, os resultados obtidos pelo extrato de *P. hysterophorus* foram estatisticamente semelhantes aos de todos os outros tratamentos testados. Com base nos resultados desta pesquisa, observou-se que a aplicação dos herbicidas e a capina apresentaram resultados superiores em todos os parâmetros testados; no entanto, ambas as abordagens são pouco sensatas: a capina é trabalhosa, ao passo que os herbicidas podem causar poluição ambiental. Por isso, o potencial herbicida de *P. hysterophorus* precisa ser incentivado para se alcançar um manejo sustentável de plantas daninhas e um alto rendimento de forma ecologicamente correta.

Palavras-chave: herbicidas, Stomp 330E, extrato de parthenium, umidade residual, controle de plantas daninhas, rendimento de sementes.

INTRODUCTION

Chickpea (*Cicer arietinum* L.) is one of the most important pulses as well as a vegetable crop in Pakistan. It contributes 75 percent to total pulses grown in Pakistan (Sibtain et al., 2015; Abbas et al., 2016). The area under chickpea cultivation in Pakistan during 2012-13 was 992 K ha with a production of 751.3 K tons with an average seed yield of 757 kg ha⁻¹. Similarly, in Khyber Pakhtunkhwa, the area of chickpea cultivation was 37.9 K ha and the production was 20.1 K tons, while the average yield was 530 kg ha⁻¹ (Pakistan Statistical Yearbook, 2016). Because chickpea is a rich and inexpensive source of energy and protein, it can help people to improve the quality of their daily nutrition (Esmaeilzadeh and Aminpanah, 2015; Tiwari and Meena, 2016). Moreover, it can also play an important role in the agricultural sustainability through its nitrogen fixation ability (Khan et al., 2012). Although it is an important crop in terms of human nutrition and soil health, its yield is declining as compared to the maximum potential of cultivars as a result of various factors. One of the key constraints is weed infestation (Hussain et al., 2015). This crop is a poor competitor with weeds particularly at earlier growth stages because of its slow growth and limited leaf area development (Abbas et al., 2016).

Weeds compete with crops for available moisture, nutrients, space and solar radiation. The most common and problematic weeds for chickpea crops include *Chenopodium album*, *Asphodelus tenuifolius*, *Argemone mexicana*, *Carthamus oxyacantha*, *Cenchrus ciliaris*, *Cyperus rotundus*, *Fumaria* sp., *Polygonum* sp., *Lathyrus* sp., *Vicia sativa*, *Cynodon dactylon* and *Cirsium arvense* (Khan et al., 2011). Annual broad-leaved weeds are more competitive to chickpea because they have a similar growth pattern to that of chickpea and severity also increases with advance in growth (Bhan and Kukula, 1987). In Pakistan, weed-induced yield losses in chickpea range between 24-63% (Abbas et al., 2016). If weeds are not properly controlled within the critical growth period, yield losses may reach 88% (Bhalla et al., 1998).

For an effective control of weeds in field crops, various mechanical, chemical and biological methods are applied (Silva et al., 2004). Mechanical methods such as hand weeding are the best and most effective but they are time-consuming and laborious (Ihsan et al., 2014). Likewise, in the chemical control method, herbicides are used to prevent yield losses caused by weeds. The use of herbicides can provide effective and economic weed control and, consequently, give similar yield values or only slightly smaller values than those of weed free treatments

(Patel et al., 2006). However, in several cases of the chemical weed control method, herbicides residues have negatively affected the yield components and nodulation of susceptible varieties of chickpea (Waqas et al., 2016).

Similarly, among innovative techniques for crop management, allelopathy offers a unique and eco-friendly approach for weed management and growth regulation (Arora et al., 2015). Allelopathy involves the synthesis and release of bioactive chemical compounds that affect the growth and development of neighboring plants (Khan et al., 2014; Safdar et al., 2014). Putnam (1988) described six classes of allelochemicals: benzoxazinones, alkaloids, cyanogenic compounds, cinnamic acid derivatives, flavonoids and ethylene from different plants. These allelochemicals have the capability of damaging the normal growth of weeds by affecting their metabolic pathways (Weston and Duke, 2003). Nevertheless, it has been reported that foliar application of allelochemicals poses a significant impact on improving physiological processes and crop yield (Shehzad et al., 2016; Ashraf et al., 2017).

Considering the importance of chickpea crops and weed-induced yield losses, the present study was designed to investigate the feasibility of using herbicides and plant extracts for control of weeds in chickpea.

MATERIALS AND METHODS

Study site and design

Field studies were performed for three years at the Agricultural Research Institute, Dera Ismail Khan, Khyber Pakhtunkhwa-Pakistan. The mean maximum and minimum temperatures of the study were 31.22 and 17.53 °C in 2011; 31.03 and 16.44 °C in 2012 and 31.49 and 16.93 °C in 2013, respectively. Likewise, average rainfall was 483 mm in 2011; it was reduced to 450 mm in 2012 and, in 2013, the recorded rainfall was 327.40 mm (Khyber Pakhtunkhwa, 2014). The experiments consisted of ten treatments replicated three times using a Randomized Complete Block design (RCBD).

Treatments

The size of each plot was 5 x 1.5 m² with five rows. Row to row distance was maintained at 30 cm. The crop was raised on the residual moisture of a previously transplanted rice crop. The treatments are detailed in Table 1. Pre-emergence herbicides were sprayed with a knapsack backpack sprayer at recommended rates immediately after sowing whereas post-emergence treatments were foliarly applied after complete emergence (8 days after sowing). For herbicide application, first of all calibration was performed to find out the exact volume of water required for each plot. For comparison among treatments, hand weeding was kept as positive control while weedy check was kept as a negative control treatment. The chickpea cultivar Karak-III was used during the current course of experimentation.

Table 1 - Detail of treatments applied in the experiment

| Treatment | Time of application | Rate |
|--------------------------------|---------------------|-------------------------|
| Stomp 330 E (full dose) | Pre-emergence | 2.5 L ha ⁻¹ |
| Stomp 330 E (half dose) | Pre-emergence | 1.25 L ha ⁻¹ |
| Dual Gold 960 EC (full dose) | Pre-emergence | 1 L ha ⁻¹ |
| Dual Gold 960 EC (half dose) | Pre-emergence | 0.5 L ha ⁻¹ |
| Isoproturon 500 EW (full dose) | Post emergence | 3 kg ha ⁻¹ |
| Isoproturon 500 EW (half dose) | Post emergence | 1.5 kg ha ⁻¹ |
| Parthenium extract | Post emergence | 200 g L ⁻¹ |
| Parthenium extract | Post emergence | 100 g L ⁻¹ |
| Hand Weeding | - | - |
| Weedy Check | - | - |

Extract preparation

For extract preparation, mature *Parthenium hysterophorus* plants were collected and kept in oven for 48 hours at 65 °C for drying. The dried samples were then ground into powder, weighed on an electrical balance and soaked in distilled water for 24 hours at two different concentrations namely, 200 g L⁻¹ and 100 g L⁻¹ (w/v, dry basis). Afterwards, the mixture was filtered through muslin cloth and the obtained extracts were kept in bottles labelled with designated concentration.

Crop husbandry

Selection of the experimental site was based on the previous history of higher weed infestation. The field was ploughed twice, after harvesting of rice when the soil was suitable for ploughing. It was followed by planking by tractor mounted implements. Chickpea was planted at a seed rate of 60 kg ha⁻¹ with a single row hand drill. No artificial irrigation was applied to the crop during its growth period.

The soil of experimental site was silty loam in texture. The pH value of saturated soil paste was 7.8 and total soluble salts were 0.91 dS m⁻¹. Soil was low in organic matter (0.78%), total nitrogen (0.08%), available phosphorus (8.2 ppm) and potassium (185 ppm). During seed bed preparation, a uniform basal dose of nitrogen and phosphorus at the rate of 40 kg ha⁻¹ was applied. There was no disease or insect attack in all trials throughout the course of experimentation. At physiological maturity, the crop was manually harvested and all yield parameters were recorded.

Data recording

Weed density was recorded by randomly throwing a 33 cm x 33 cm quadrat three times in each plot. Weeds inside the quadrat were counted and identified. The mean was calculated and was then converted into density m⁻². Fresh weed biomass was calculated by harvesting all weeds inside the quadrat and weighing them in g m⁻². Similarly, for measuring various plant parameters such as plant height and number of branches per plant, ten representative plants were randomly chosen and tagged and their length was measured from base to tip in centimeters; subsequently, the means were computed. Biological yield and seed yield were measured in kg and then converted into kg ha⁻¹.

Statistical Analysis

The data recorded for each trait individually underwent the ANOVA technique by using the computer software MSTATC. The parameters significant (P<0.05) in ANOVA were subsequently subjected to the Least Significant Difference (LSD) test for comparison (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Weed density (m⁻²)

The statistical analysis of the data revealed that weed density (m⁻²) was significantly affected by all the assigned treatments during the three-year studies (Figure 1). During the first year (2010-11), the lowest weed density (84 m⁻²) was found for Stomp 330E applied at full dose, followed by Dual Gold 960EC at full dose, while maximum weed density (171 m⁻²) was measured in weedy check plots. Similarly, during the second and third years (2011-12 and 2012-13), the same trend was found: minimum weed density (69.5 and 55 m⁻²) was recorded in experimental plots sprayed with the full dose of Stomp 330E. Dual Gold 960EC was ranked second in terms of weed control efficiency during the entire experimental duration. Treatment comparison showed that the full dose of all the tested herbicides resulted in maximum weed suppression. For plant extract, weed density was higher than full doses of herbicides but lower than the weedy check. However, the values of weed density for plant extract were statistically similar to the half doses of the applied herbicides (Figure 1).

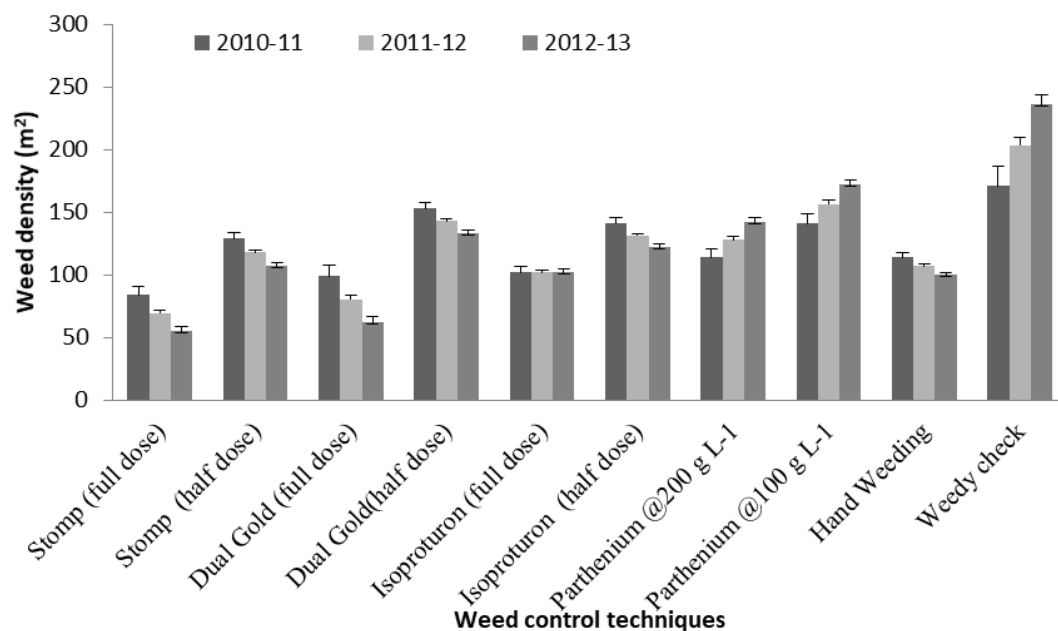


Figure 1 - Effect of different weed control techniques on weed density (m⁻²) in chickpea.

There were differences in weed density among the study years which could be attributed to differential rainfall during three years of study. However, highly significant differences were found for all the weed control treatments. It was noted that pre-emergence herbicides showed a momentous effect towards weed suppression in comparison to post-emergence herbicides. Current results are in a great analogy with those found by Muhammad et al. (2011), who reported that pre-emergence herbicides, i.e. Stomp 330E and Dual Gold 960EC with application rate of 3.50 and 2.50 liter ha⁻¹, control weeds up to 94.6 and 90%, respectively. Similarly, the potential of herbicides for weed suppression has also been stated by Patel et al. (2006). They found that application of herbicides significantly reduced weed density compared to weedy check. Low weed population in herbicide-treated plots was due to long persistence of chemicals in soil, which inhibited weed seed germination (Marwat et al., 2003). Furthermore, recent studies have been conducted in which maximum weed control and high yield were achieved with integration of hand weeding and pre-emergence herbicide application. For example, the study of Rao et al. (2015) showed that pre-emergence application of Stomp 330E followed by hand weeding at 50 days after sowing resulted in maximum weed control and better crop yield than hand weeding alone. However, such type of integration approach depends on the socioeconomic conditions of growers. This approach can be advantageous in areas with cheap labor cost or high value crops.

Fresh weed biomass (g m⁻²)

Figure 2 shows the data on fresh weed biomass as affected by various weed management techniques in chickpea crop. The results show slight variations in fresh biomass accumulation during the three-year period of the study. It was found that, as with weed density, the least biomass accumulation (less than 500 g m⁻²) was found with Stomp 330E (full dose). These values were statistically similar to the positive control treatment, i.e., hand weeding. Fresh weed biomass in hand weeding was 405, 362 and 320 g m⁻² for the years 2010-11, 2011-12 and 2012-13, respectively. Similarly, biomass accumulation as a result of plant extract application was found to be statistically similar in comparison to all other pre and post-emergence herbicides. This showed that the plant extract is capable of suppressing weed germination and growth. Ashraf et al. (2017) stated that plants have various types of bioactive compounds that can be used as herbicides for weed management. Likewise, the research study of Shah et al. (2016) reported that use of plant allelochemicals is an economical and ecofriendly solution for weed management.

The present results are in close proximity with the findings of Patel et al. (2006), who reported the lowest weed biomass accumulation with hand weeding and Stomp 330E. Long persistence of

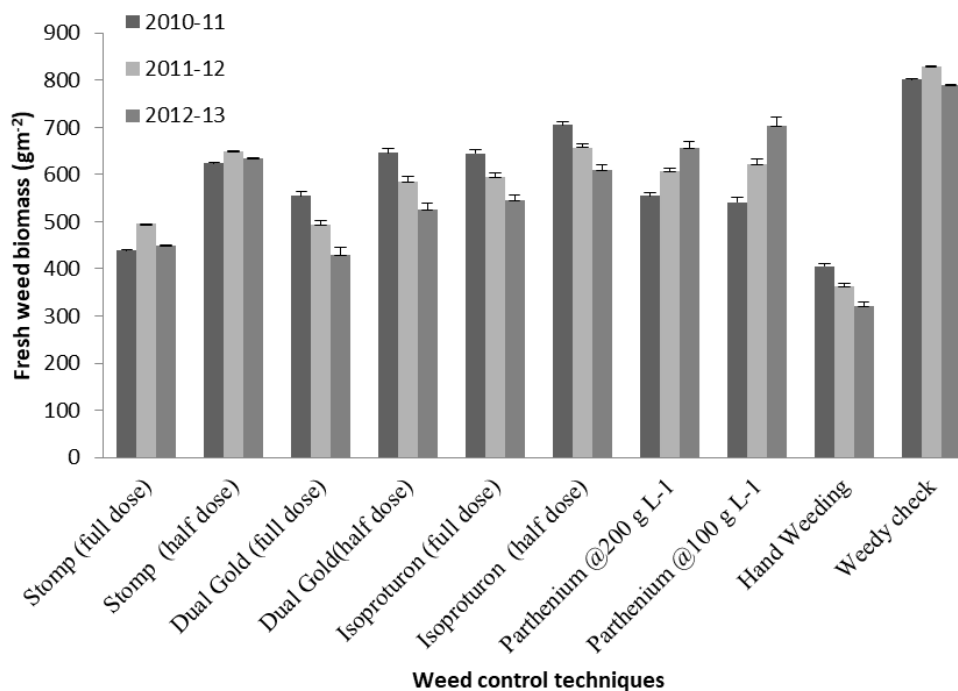


Figure 2 - Effect of different weed control techniques on fresh weed biomass (g m⁻²) in chickpea.

herbicides on the soil negatively affects weed growth and weed biomass. Likewise, Avola et al. (2008) and Kumar et al. (2015) also reported that the lowest weed density and weed biomass were found after use of manual weeding and pre-emergence herbicides. The bare minimum biomass accumulation in hand weeding plots was due to poor growth of weeds as a result of regular weed removal whereas weedy check plots were left untreated throughout the growing season, which resulted in the highest weed density.

Plant height (cm) and number of branches per plant

The data revealed that different treatments had a significant effect on plant height (Figure 3) and number of branches per plant (Figure 4). The analysis of the data showed that the plots treated with the full dose of Stomp 330E resulted in the highest plant height of 49.53, 53.09 and 56.66 cm and number of branches per plant during the duration of the study i.e. 2010-11, 2011-12 and 2012-13, respectively. These values were found to be statistically similar to Dual Gold 960EC (Full dose), hand weeding and *P. hysterophorus* extract. However, the results of pre-emergence herbicides were statistically similar to those of the tested post-emergence herbicide for both crop growth parameters. Khan et al. (2012) also found a non-significant effect on growth under the application of pre and post-emergence herbicides.

The overall results showed non-significant changes in chickpea plant height throughout the duration of the study while there was an increase in number of branches per plant in the third year of the research study. The higher plant height and the larger number of branches in herbicide-treated plots might be due to the fact that herbicides greatly reduced weed infestation, which really provides favorable growing conditions for better crop growth (Batish et al., 2007). These results are supported by the findings of Muhammad et al. (2011) and Emenky et al. (2010), who reported maximum plant height in plots where the crop was kept weed-free after use of herbicides and manual weeding. In addition to management techniques, the use of Karak-III cultivar also played a role behind the satisfactory results. It has been proved that the morphological characteristics of the cultivar Karak-III led to maximum branching, sufficient resource capturing capability, early maturity and weed tolerance capacity as compare to other chickpea cultivars (Waqas et al., 2016). Current investigations are in correspondence with the results of Gul et al. (2011), who found the best growth, maximum branches and higher seed yield in Karak-III as compared to other chickpea cultivars.

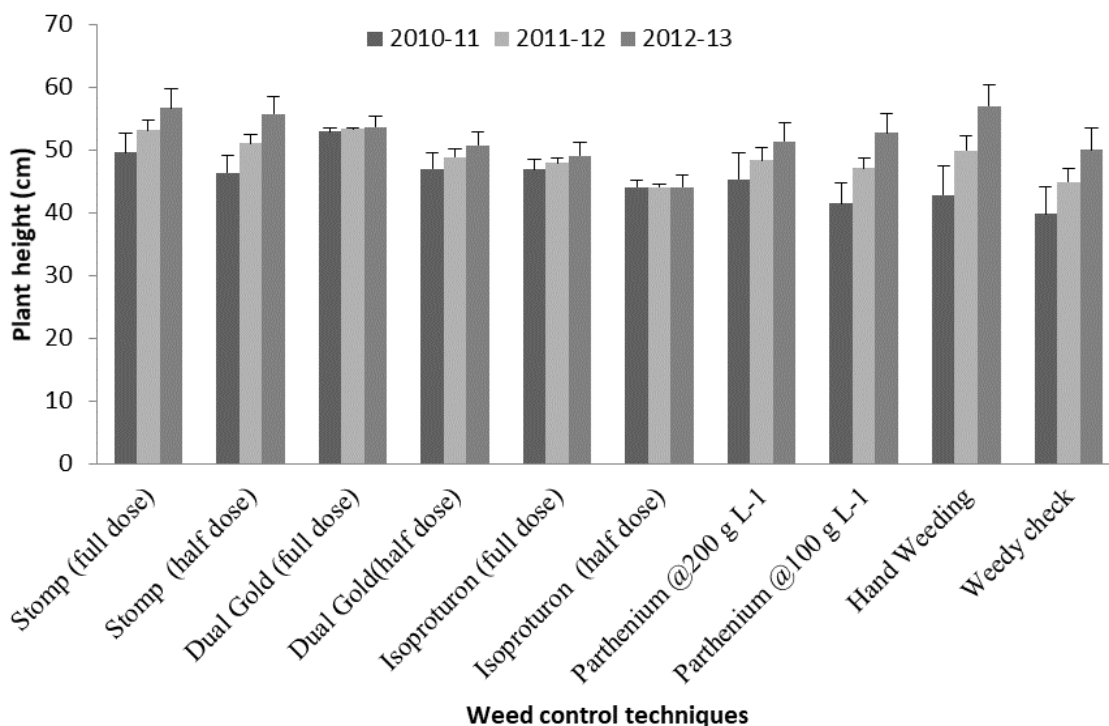


Figure 3 - Effect of different weed control techniques on plant height (cm) in chickpea.

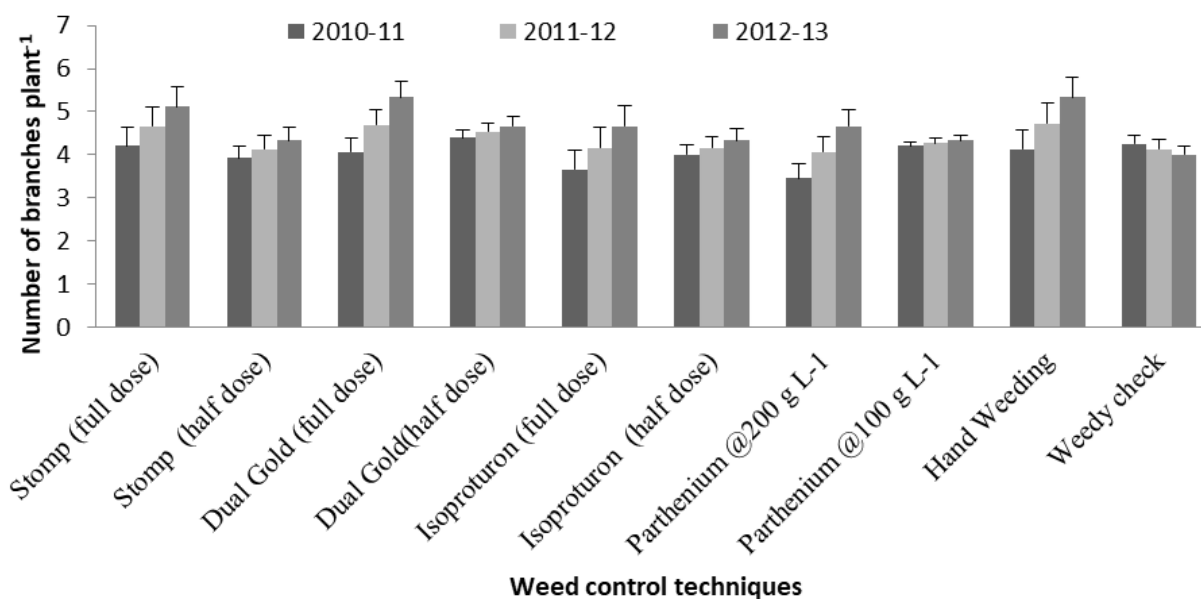


Figure 4 - Effect of different weed control techniques on number of branches per plant in chickpea.

Biological yield and seed yield (kg ha^{-1})

The data in Figures 5 and 6 showed that different weed control measures had a remarkable effect on the biological yield and the seed yield of chickpea. The results showed that during the three years of the experiment, there was a slight change in biological yield of chickpea. However, through the entire study duration, maximum biological yield (4256.9, 3627.6 and 3208.3 kg ha^{-1}) was recorded for Stomp 330E at full dose, followed by full dose of Dual Gold 960EC whereas the least biological yield was found in the weedy check (Figure 5). The biological yield for Stomp 330E was higher than the positive control (hand weeding), which showed that herbicides were more effective in terms of weed control and crop yield.

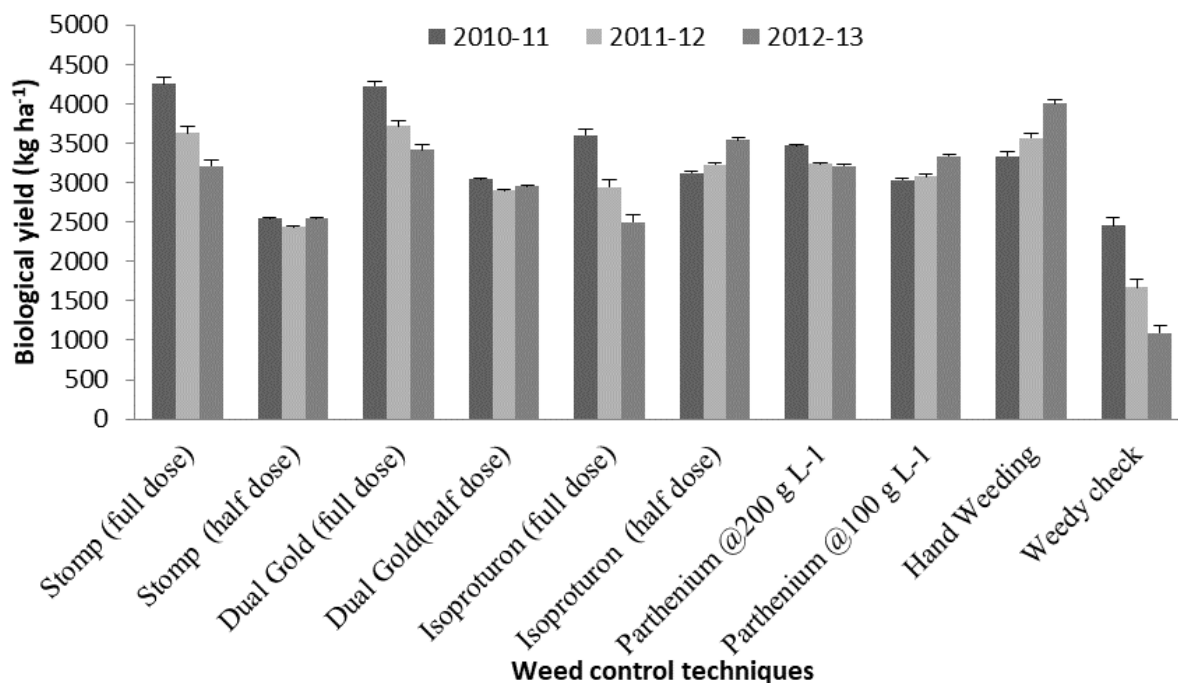


Figure 5 - Effect of different weed control techniques on biological yield (kg ha⁻¹) of chickpea.

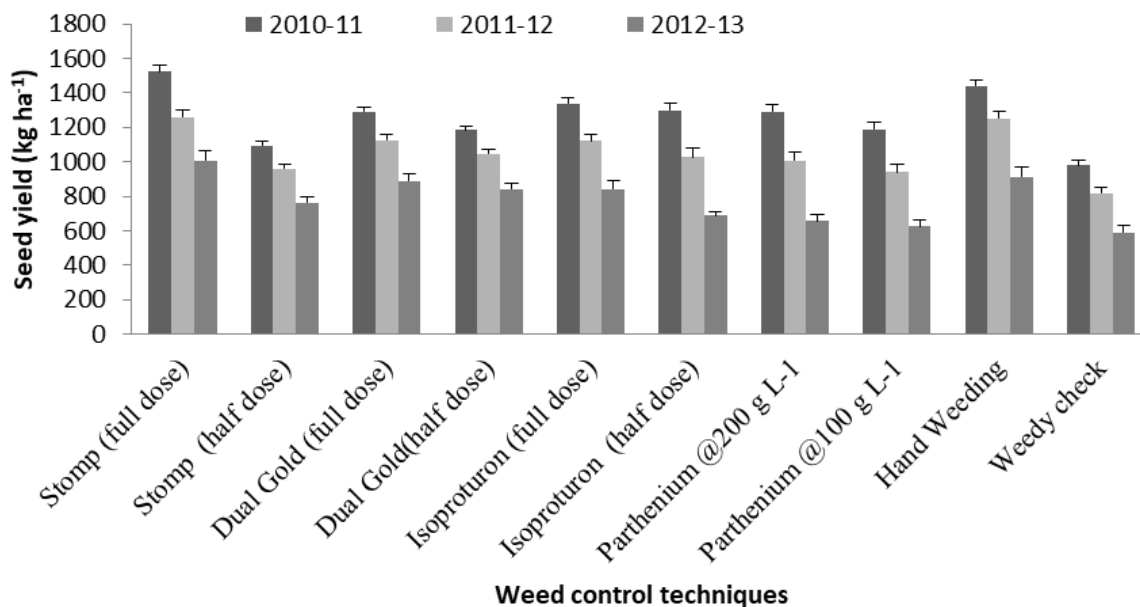


Figure 6 - Effect of different weed control techniques on seed yield (kg ha⁻¹) of chickpea.

Similarly to biological yield, seed yield was also significantly affected by various weed control strategies. However, there was a reduction in seed yield during the second and third years of experimentation (Figure 6). The probable reason behind this reduction was lower precipitation in the reported year (2012-13). During 2010-11, the highest seed yield (1522.2 kg ha⁻¹) was recorded for Stomp 330E applied at full dose followed by Dual gold 960EC, Isoproturon 500EW and *P. hysterophorus* extract. Seed yield during 2011-12 was reduced to 1257.44 kg ha⁻¹ while in 2012-13 it reached only 1008.7 kg ha⁻¹, and there was a similar trend for seed yield for all the applied treatments (Figure 6). The highest biological yield and seed yield in Stomp 330E were due to low weed crop competition (low weed density) and optimal use of resources (nutrients, solar radiations, water and space) (Tewari and Tiwari, 2004; Daur et al., 2008). Findings of the current study agree with those of Chaudhary et al. (2011), Khan et al. (2012) and

Chandrakar et al. (2015), who reported the highest biological yield and seed yield under the application of Stomp 330E and hand weeding.

Moreover, the post-emergence application of plant extract and herbicides also affected the biological yield of chickpea. It was found that, in comparison to the full dose of Isoproturon 500EW, the highest biological yield and seed yield resulted in *P. hysterophorus* (Figures 5 and 6). This showed that the plant extract of *P. hysterophorus* possesses the stimulatory capability of enhancing plant growth and development. This stimulatory effect, which results from foliar application of plant extracts, has been reported to improve crop growth and immunization against various biotic and abiotic stresses (Narwal, 2013). Foliar application of allelochemicals improves crop growth and yield by affecting various physiological processes, such as photosynthesis, cell division and elongation (Abbas et al., 2017). Moreover, plant extracts are harmless to grazing animals and beneficial insects (Jamil et al., 2009). They are more easily degradable than synthetic agrochemicals because of their short half-life with no toxic ring structures and low halogen substitution (Kordali et al., 2009; Jabran et al., 2010).

Based on the findings of this 3 year research study, it is concluded that Stomp 330E proved most superior in controlling weeds and, consequently, achieving better crop growth and yield. However, the non-judicious use of synthetic herbicides for crop management can cause soil and water pollution. Thus, the herbicidal potential of different allelopathic plants should be utilized as observed in this study, in which the plant extract of *P. hysterophorus* showed momentous effects towards weed suppression and crop growth along with its additional benefit of environmental sustainability.

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