Assessment of weed management practices on weed control and productivity as evidenced by economics and energetics analysis in groundnut

Abstract

A field experiment was conducted during *kharif* 2021 to assess the effect of various weed management practices in groundnut at Agronomy Instructional Farm, C. P. College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar on loamy sand soil. Among different treatments, two hand weeding at 20 and 40 DAS, interculturing and hand weeding at 15 and 30 DAS, post-emergence application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165+80 g/ha and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha have recorded lower % of category wise weed density (sedges, grasses, broad leaf weeds and total weeds) resulting in significantly higher pod and haulm yield in two hand weeding at 20 and 40 DAS (1980 and 3082 kg/ha, respectively) which was found at par with interculturing and hand weeding at 15 and 30 DAS (1892 and 2950 kg/ha, respectively), post-emergence application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165+80 g/ha (1835 and 2864 kg/ha, respectively) and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (1800 and 2811 kg/ha, respectively) as compared to unweeded check (846 and 1333 kg/ha, respectively) apart from witnessing higher gross monetary returns, net monetary returns, net energy returns, energy use efficiency, energy productivity due to effective control of grasses, sedges, broad leaf and total weeds in these treatments as compared to unweeded check.

Key words: Category wise weed density, Groundnut, Economics, Energetics, Weed control, Yield

Introduction

Groundnut (*Arachis hypogaea* L.) is one of the most important food, fodder and cash crop for the farmers of India and World. It is also known as peanut, earthnut, monkeynut, manilanut, pandanut as well as goober nut. Groundnut is rich source of oil (48%), high quality protein (21.4-36.4%) and also known for its fairly good source of some dietary minerals. India ranks first in area and second in production after China. In India, groundnut is cultivated on 6.01 mha area with a production of 10.24

mt and productivity of 1703 kg/ha (Anon., 2023). In India 80 per cent of the groundnut area and 84 per cent of the production is confined to the states of Gujarat, Andhra Pradesh, Telangana, Tamil Nadu, Karnataka and Maharashtra. In India, Gujarat holds first position in groundnut production and contributes 35.50% to the area (2.16 mha) and 40.42% to the production (4.13 mt) with an average productivity of 19.08 q/ha (Anon., 2022). In Gujarat, groundnut is cultivated during *kharif* as well as summer seasons. The groundnut cultivation in Gujarat is largely confined to Junagadh, Jamnagar, Rajkot, Amreli, Saurashtra, Banaskantha and Bhavnagar districts. The Saurashtra region of Gujarat is considered as 'Bowl of groundnut'. However, recently it has also been noticed that the area under groundnut cultivation is increasing in potato growing belt of North Gujarat because of suitable agro-climatic conditions and coarse texture of soil.

Weed infestation is the major biotic factor responsible for low productivity of groundnut. Though groundnut is a hardy crop still it is highly susceptible to weed preponderance due to small canopy and slow initial growth. In India, yield loss in groundnut due to weeds ranged from 45–71% (Gharde *et al.*, 2018), however it depends on type of weed flora associated with groundnut. As groundnut is grown mainly in the rainy season when the condition are more favorable for weed growth, that encourage repeated flushes of grasses and broad leaved weeds during the entire season for competition with the crop. This competition is more severe during the initial and critical stages. Thus, weed control during the critical period of crop-weed competition is the foremost critical production factor in groundnut. Generally weeds are controlled through hand weeding in groundnut, but it is expensive, laborious and sometimes continuous rains will interfere with timely weed control and often damage the economic produce. However, the availability of labour at the required time and at nominal cost will have direct impact on profitability of the crop. Under those conditions, the use of herbicide may become one of the best alternative to control the weeds and to achieve the acceptable profits. Considering these facts and views, an experiment on weed control in groundnut to improve the productivity was conducted.

Material and methods

A field investigation was conducted during *kharif* season 2021 at Agronomy Instructional Farm, Department of Agronomy, Chimanbhai Patel College of Agriculture, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Banaskantha (North Gujarat Agro-climatic region (AES IV) of Gujarat). The experimental plot was located at 24^o 19' North latitude and 72^o 19' East longitude with an elevation of 154.52 meters above the mean sea level. The soil of experimental field was loamy sand in texture with slightly alkaline in reaction, electrical conductivity within safe limit. The soil was low in organic carbon and available nitrogen, medium in available P_2O_5 and available K_2O and deficient in available S. The experiment was conducted comprising ten treatments with four replications. The experimental field was first ploughed by a tractor-drawn cultivator, then it was harrowed and planked. Ten days before sowing, well decomposed FYM @ 5 t/ha was applied to all the plots. The groundnut seeds of cultivar "TG 37" were treated with chlorpyriphos 20 EC @ 25 ml/kg seed and were sown manually at a spacing of 45 cm × 10 cm at a depth of 4 to 5 cm on 1st July, 2021 with a seed rate of 120 kg/ha. The fertilizer dose of 12.5:25:20 kg NP_2O_5S/ha was applied at sowing through DAP, urea and bentonite sulphur sources. The gross and net plot size of the experiment were 5.0 m × 4.5 m and 4.0 m × 2.7 m, respectively. The first irrigation was given immediately after sowing and next irrigation was given eight days after sowing for ensuring proper germination and establishment of the seed. Remaining irrigations were given as per requirement of crop. Chlorphyriphos was applied @ 1.0 lit/ha at 65 DAS by mixing it with fine sand to control the termite insects. All the weather conditions were optimum for the normal growth and development of crop with 429.5 mm rainfall received during the experimental period. The crop was harvested manually at physiological maturity from the respective separate net plots and later the yields were converted into hectare basis. In interculturing treatment, interculturing was done by using manually operated cycle weeder. The spaying of different herbicides was done by using knapsack sprayer with flat fan nozzle having 15 litre capacity. All the pre and post-emergence herbicides (Required quantity of trade formulation) were applied at one DAS and 30 DAS, respectively with a spray volume of 500 litres /ha. The weed flora density (No./0.25 m^2) from each plot was recorded at two spots at 30, 60 DAS and at harvest by using 50 cm × 50 cm quadrate at random locations and was averaged over two spots. Further, the data was multiplied with four to convert the data into No./m^2. Based on the weed density (No./m^2) data, the category wise % weed density over unweeded check (100%) was calculated for at various stages using the following formula.

$$\text{Per cent weed density} = \frac{\text{Weed density (No./m}^2\text{) of a treatment}}{\text{Weed density (No./m}^2\text{) of unweeded check}} \times 100$$

All the yield and other observations of groundnut were measured using standard procedures. The statistical analysis of the data collected for different parameters were carried out following the standard procedures as suggested by Gomez and Gomez (1984).

Results and Discussion

Effect on weed flora

The different weed species observed at 30, 60 DAS and harvest (Table 1 to 3) were *Cyperus rotundus* L. among sedges, *Cynodon dactylon* L., *Digitaria marginata* L., *Digitaria sanguinalis* L. and *Dactyloctenium aegyptium* L. among grasses and *Portulaca oleracea* L., *Boerhavia erecta* L., *Tribulus terrestris* L, *Leucas aspera*., *Digeria arvensis* L., *Commelina benghalensis* L. and *Amaranthus viridis* among broad leaf weeds. Among, sedges *Cyperus rotundus* L., among grasses *Cynodon dactylon* L. and among broad leaf weeds *Digeria arvensis* L. were dominant at all stages (30, 60 DAS and harvest). Overall, the field was dominated with broad leaf weeds which was followed by grasses and sedges. The weed flora and their emergence is attributed to soil weed seed bank, difference in tillage intensity, earlier cropping system, weather parameters, congeniality of soil environment *etc.* (Hatti *et al.,* 2018).

Effect on per cent relative weed density

The effect of different weed management practices on per cent relative weed density at 30 DAS, 60 DAS and at harvest is given in Fig. 1. The appraisal of data revealed that the relative weed density (%) at 30 DAS, 60 DAS and at harvest were drastically affected by different weed management practices. The two hand weedings at 20 and 40 DAS recorded lower relative weed density (%) of sedges, grasses, broad leaf and total weeds at 30 DAS (30.9, 29.4, 16.1 and 23.5%, respectively) which was closely followed by interculturing and hand weeding at 15 and 30 DAS (32.3, 32.5, 17.2 and 25.4%, respectively), pre-emergence application of sulfentrazone 28 + clomazone 30 WP @ 350 + 375 g/ha (40.2, 36.1, 20.4 and 29.5%, respectively) and diclosulam 84 WDG @ 22 g/ha (47.4, 34.2, 22.0 and 30.7%, respectively). Whereas, post-emergence herbicides *viz.*, sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha, imazethapyr 10 SL @ 100 g/ha, fluthiacet-methyl 10.3 EC @ 13.6 g/ha, imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha and unweeded check have recorded comparatively higher relative weed density (%) of sedges, grasses, broad leaf and total weeds. The lower relative weed density (%) of sedges, grasses, broad leaf weeds and total weeds recorded under two hand weeding at 20 and 40 DAS and interculturing and hand weeding at 15 and 30 DAS was mainly due to effective destroying of standing weeds through mechanical and cultural efforts. Further, the lower relative weed density (%) of weeds recorded under pre-emergence application of sulfentrazone 28 + clomazone 30 WP @ 350 + 375 g/ha and diclosulam 84 WDG @ 22 g/ha was due to lower weed count of category wise and total weeds observed in those plots. The sulfentrazone + clomazone inhibit the protoporphyrinogen oxidase enzyme in sensitive weeds thereby affects membranes disruption and inhibits photosynthesis. Whereas, diclosulam kills the aceto lactate synthase (ALS) enzyme in the targeted weed plants which ultimately stops amino acids synthesis. Mavarkar *et al*. (2015) witnessed lower weed dry weight and higher WCE under two HW at 20 and 40 DAS + two IC at 30 and 45 DAS in groundnut as compared to weedy check. The similar findings were also explained by Kalhapure *et al*. (2013) and Rana *et al*. (2019). On the other hand, Rawat *et al*. (2017) at Madhya Pradesh noticed lower dry weight of weeds under application of sulfentrazone and clomazone. Further, Nainwal *et al*. (2013) and Kumar *et al*. (2020) also proved lower dry weight of weeds due to application of diclosulam. The higher relative weed density (%) of sedges, grasses, broad leaf weeds and total weeds recorded under unweeded check was resultant of unchecked weed growth due to no weed check activities.

Screening of data on relative weed density (%) of weeds at 60 DAS and at harvest as influenced by weed management practices highlighted that, two hand weedings at 20 and 40 DAS has envisaged a very low relative weed density (%) of sedges, grasses broad leaf and total weeds (13.1-12.4, 22.9-20.6, 14.9-13.4 and 17.1-15.5%, respectively) and was closely followed by interculturing and hand weeding at 15 and 30 DAS (14.5-13.9, 23.8-20.8, 16.8-14.9 and 18.6-16.6%, respectively), post emergence application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (14.2-14.2, 24.4-22.3, 18.0-15.6 and 19.2-17.5%, respectively) and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (18.9-18.2, 30.7-28.0, 20.6-19.1 and 23.5-21.8%, respectively) as compared to other treatments. Nevertheless, the maximum relative weed density (%) of sedges, grasses, broad leaf and total weeds were observed under unweeded check (100-100, 100-100, 100-100 and 100-100%, respectively). The lower relative weed density (%) at 60 DAS and at harvest recorded under two hand weedings at 20 and 40 DAS as well as interculturing and hand weeding at 15 and 30 DAS treatments is due to consequence of near complete removal of weeds through hand weeding and intecultivation methods at both stages of groundnut crop. The present outcomes were also supported by Patel *et al*. (2013), where they found lower weed dry weight of weeds under two hand weeding + two interculturing at 20 and 40 DAS. Further, the lower relative weed density (%) witnessed under PoE application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha was a resultant of selective killing of targeted weeds as discussed above. The lower weed relative weed density (%) in these treatments at 60 DAS and at harvest is due to better efficacy and prolonged effectiveness of applied herbicides and hand weeding which reduced weed growth. As PoE application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha combination suppress protoporphyrinogen oxidase enzyme, thereby causing membranes disruption and photosynthesis and acetyl CoA carboxylase (ACC-ase) enzyme reduce fatty acid synthesis in the selected target weeds, it has recorded lower relative weed density (%) of sedges, grasses, broad leaf weeds and total weeds. Whereas, lower relative weed density (%) of category wise and total weeds in imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha is ascribed to its chemical nature and weed control ability. Thus, the post-emergence pre-mix herbicide combinations have also successfully controlled the category wise and total relative weed densities (%). Harithavardhini (2016) also realized lower weed dry weight under PoE application of acifluorfen sodium 16% EC + clodinafop propargyl 8% and PoE application of imazethapyr + imazamox in soybean.

Effect on crop growth and yield parameters

The data belong to to crop growth and yield parameters and yield of groundnut as influenced by different weed management practices are presented in Table 4. Among various weed management practices, two hand weedings at 20 and 40 DAS recorded significantly higher dry weight of nodules at 45 DAS (72.30 mg/plant) and was found on par with interculturing and hand weeding at 15 and 30 DAS (67.78 mg/plant) and unweeded check (767.49 mg/plant). Whereas, all other herbicidal treatments have recorded comparatively lower dry weight of nodules at 45 DAS (44.44 – 60.86 mg/plant). Significantly lower dry weight of nodules chiefly due to application of post-emergence herbicides at 30 DAS *i.e.*, just before flowering (at 45 DAS) which hampered the nodulation activity due to application of post-emergence herbicides. These results are in line with the findings of Sudharshana *et al.* (2013) who quoted that application of imazethapyr @ 150 g/ha in groundnut adversely affected the nitrogenase activity and resulted in significantly lower total nodules and active nodules up to 45 DAS. Whereas, the pre-emergence application of herbicides *viz.*, pendimethalin 38.7 CS, diclosulam 84 WDG and sulfentrazone 28 + clomazone 30 WP registered lower values of dry weight of nodules next to hand weeding at 20 and 40 DAS, interculturing and hand weeding at 15 and 30 DAS and unweeded check might be due to sufficient time gap available for the recovery from herbicidal effects of these chemicals on soil and plants. Significantly higher dry weight of nodules recorded under hand weeding at 20 and 40 DAS which were principally due to loosening of soil particles and proper soil aeration through hand weeding, which might have increased the soil microflora and ultimately root nodulation activities. Inetrculturing and hand weeding at 15 and 30 DAS and unweeded check have also recorded on par results with hand weeding at 20 and 40 DAS due to no chemicals application. Rupareliya *et al*. (2020) furthermore observed higher number and dry weight of root nodules/plant under interculturing and hand weeding at 15 and 30 DAS in soybean.

Weed management practices have significantly influenced the plant height, total dry matter production, number of filled pods per plant, pod yield per plant, pod yield, haulm yield and biological yield (Table 4). An exploration of data stipulated that, among different treatments two hand weedings at 20 and 40 DAS recorded significantly higher plant height at 90 DAS, total dry matter production, number of filled pods per plant, pod yield per plant resulting in significantly higher pod yield, haulm yield and biological yield (49.29, 41.11 g/plant, 21.70, 9.63 g/plant, 1980 kg/ha, 3082 kg/ha and 5063 kg/ha, respectively) which was statistically at par with interculturing and hand weeding at 15 and 30 DAS (46.26, 39.51 g/plant, 20.90, 9.47

g/plant, 1892 kg/ha, 2950 kg/ha and 4844 kg/ha, respectively), post-emergence application sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (45.61, 38.39 g/plant, 20.40, 9.32 g/plant, 1835 kg/ha, 2864 kg/ha and 4700 kg/ha, respectively) and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (45.02, 37.80 g/plant, 20.15, 9.31 g/plant, 1800 kg/ha, 2811 kg/ha and 4612 kg/ha, respectively). However, the treatment unweeded check recorded significantly lower plant height at 90 DAS, total dry matter production, number of filled pods per plant, pod yield per plant resulting in significantly lower pod yield, haulm yield and biological yield (21.47, 20.16 g/plant, 9.38, 4.40 g/plant, 846 kg/ha, 1333 kg/ha and 2181 kg/ha, respectively). Whereas, number of kernels per pod, seed index and shelling % were not significantly differed by different weed management practices.

Significantly higher pod yields recorded under two hand weeding at 20 and 40 DAS, interculturing and hand weeding at 15 and 30 DAS, sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha was directly attributed to better dry matter production, no. of filled pods per plant, pod yield per plant which is directly due to lower crop -weed competition as a resultant of effective suppression of weeds as indicated by lower relative weed density (%) and weed density of grasses, sedges, broad leaf weed and total weeds (Table 1 to 3 and Fig. 1) under "Effect on per cent relative weed density" subheadings in these treatments.

The better yield attributes were mainly due to effective suppression of weeds by uprooting and removal of weeds through physical and mechanical efforts which drastically reduced the densities and dry weights of sedges, grasses, broad leaf and total weeds which facilitated better crop growth by providing congenial environment for growth and development as evident from increase in plant height and dry matter production, improvement in growth parameters which might be due to increased water and nutrient uptake, which might have accelerated photosynthetic rate, thereby increasing the supply of carbohydrates resulted in cell division, multiplication and elongation, increased peg initiation and development as well as better partitioning of photosynthates leading to better yield parameters like number of pods per plant, number of filled pods per plant as well as pod yield per plant and ultimately enhanced the pod and haulm yields of groundnut.

The improvement in number of pods per plant, number of filled pods per plant, pod yield per plant under post-emergence application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha was attributed to the better control of weeds *viz.*, sedges, grasses and broad leaf weeds (Table 1 to 3) that resulted in less competition of weeds for growth resources in these treatments that resulted in increased crop growth, resource utilization by the crop, efficient production, partitioning and translocation of photosynthates which finally turned into higher pod and haulm yield of groundnut. Ram *et al*. (2011) observed higher yield attributing characters *i. e.,* number of pods per plant, seeds per pod and seed yield over weedy check in field pea under two hand weeding at 20 and 40 DAS. Kalhapure *et al*. (2013) also outlined the similar findings as that of above results. In groundnut crop, Sharma *et al*. (2015) also supported the findings of present study through higher growth, yield attributes and yield of groundnut under hand-weeding and inter-culturing at 20 and 40 DAS and sodium acifluorfen + clodinafop-propargyl. Deshmukh *et al.* (2018) also supported the outcomes through higher dry matter accumulation, pods per plant, seed and straw yield under imazethapyr + imazamox 70% WG in greengram. On the other hand, unweeded check recorded significantly lower number of pods per plants, filled pods per plant and pod yield per plant which ultimately reduced pod yield and haulm yields due to severe and magnificent growth of weeds as compared to all other weed control. These findings are in agreement with those of Rana *et al.* (2019) and Rupareliya *et al*. (2020) Verma and Choudhary (2020).

Effect on economics

The ultimate aim of any agricultural technique/technology/practice is to obtain maximum income/returns per rupee invested. Hence, the calculation of economics is essential. This also gives a clear idea about the optimum level/type of practice/input that could be used/adopted to obtain maximum net profit. The glimpse of data tabulated in Table 5 indicated that among different weed management practices, two hand weedings at 20 and 40 DAS gave higher gross returns (₹ 114410/ha) which was followed by interculturing and hand weeding at 15 and 30 DAS (₹ 109350/ha), post-emergence application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (₹ 106070/ha) and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha

(₹ 104055/ha). Lowest gross returns was observed under unweeded check (₹ 48965/ha). The differences in gross returns were purely ascribed to their respective pod and haulm yields. The net returns of various weed management practices have also been worked out looking into gross returns and cost of cultivation. The data pertaining to net returns of groundnut under the influence of weed management practices explained that maximum net returns of ₹ 53226/ha was obtained with two hand weeding at 20 and 40 DAS followed by post-emergence application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (₹ 51272/ha), interculturing and hand weeding at 15 and 30 DAS (₹ 50076/ha) and post-emergence application of imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (₹ 49552/ha). The variation in net returns among these weed management practices was because of variation in the gross returns and cost of cultivation in these treatments. Whereas, lower net returns of ₹ -2559/ha was obtained in unweeded treatment which indicates lower returns than cost of cultivation due to poorer pod and haulm yields recorded under unweeded check. It is evident from the data on B:C ratio that, all the weed management practices have increased B:C ratio as compared to weedy check treatment. A maximum B:C ratio of 1.94 was obtained under post-emergence application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha which was closely followed by post-emergence application of imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (1.91), two hand weeding at 20 and 40 DAS (1.87) and interculturing and hand weeding at 15 and 30 DAS (1.84). The higher B:C ratio documented under sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha than two hand weeding at 20 and 40 DAS, interculturing and hand weeding at 15 and 30 DAS and other treatments was primarily due to lower cost of cultivation in these above herbicidal treatments.

Even though the pod and haulm yields were higher (1892-1980 kg/ha and 2950-3082 kg/ha, respectively) under two hand weeding at 20 and 40 DAS, interculturing and hand weeding at 15 and 30 DAS treatments over other herbicidal treatments, still these treatments have recorded lower B:C ratio because of higher cost of cultivation of these treatments (₹ 59274 - 61184/ha) than other following herbicidal treatments. These results are in confirmatory with the findings of Yadav *et al*. (2015) who observed maximum net returns (₹ 17135/ha) and benefit-cost ratio (2.35) with PoE application of imazethapyr + imazamox (pre-mix) @ 0.05 kg/ha in blackgram over other treatments on sandy loam soils of Gwalior, Madhya Pradesh. Further, studies conducted by Jagadesh *et al.* (2019) also supported the present findings by revealing that more profitability with higher net return (₹ 44653/ha) and benefit cost ratio (2.1) with investing lowest expenditure (₹ 39240/ha) could be achieved with application of pendimethalin @ 1 kg/ha on 3 DAS *fb* acifluorfen sodium (16.5%) + clodinafop propargyl (8% EC) @ 187.5 g/ha on 20 DAS over hand weedings at 15 and 30 DAS and weedy check.

Effect on energetics

Although agriculture only accounts for a small portion of global energy consumption, it is widely acknowledged that it is essential given how heavily current methods for expanding productivity rely on energy-intensive inputs. In order to replace expensive energy generated outside of agriculture, it is thus required to discover ways to reduce the usage of expensive and quickly depleting fossil fuels, to create other energy sources, and to better use the energy sources already available in agriculture (Adamowicz, 1981). In this regard, the accounting of energy input and output was done to calculate net energy returns, energy use efficiency etc. to compare different weed management practices. The different weed management practices varied in terms of input energy, output energy, net energy returns, energy use efficiency, energy productivity and specific energy as indicated in Table 5. Among various weed management practices, two hand weedings at 20 and 40 DAS recorded higher input energy, output energy, net energy returns, energy use efficiency, energy productivity and lower specific energy (9153 MJ/ha, 67631 MJ/ha, 58478 MJ/ha, 7.39, 0.22 Kg/MJ and 4.62 MJ/kg, respectively) which was followed by interculturing and hand weeding at 15 and 30 DAS (9058 MJ/ha, 64687 MJ/ha, 55630 MJ/ha, 7.14, 0.21 Kg/MJ and 4.79 MJ/kg, respectively), post-emergence application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (8963 MJ/ha, 62775 MJ/ha, 53811 MJ/ha, 7.00, 0.20 Kg/MJ and 4.88 MJ/kg, respectively) and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (8872 MJ/ha, 61598 MJ/ha, 52726 MJ/ha, 6.94, 0.20 Kg/MJ and 4.93 MJ/kg, respectively). Wherein, unweeded check recorded lower input energy, output energy, net energy returns, energy use efficiency, energy productivity and higher specific energy (8821 MJ/ha, 29099 MJ/ha, 20278 MJ/ha, 3.30, 0.10 Kg/MJ and 10.43 MJ/kg, respectively).

The higher input energy witnessed under two hand weedings at 20 and 40 at 40 DAS and interculturing and hand weeding at 15 and 30 DAS treatments was due to maximum input energy required as the manual labours were used for hand weeding and interculturing operations. Whereas, comparatively lower energies recorded under other herbicidal treatments is ascribed to difference in dosage of herbicides. Nevertheless, lower energy input under unweeded check revealed the direct impact of no/nil energy used for weed control operations. Whereas, elevated vales of output energy, net energy returns, energy use efficiency, energy productivity and lower specific energy under two hand weedings at 20 and 40 DAS, interculturing and hand weeding at 15 and 30 DAS, post-emergence application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha and imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha were solely attributed to their relevant higher pod and haulm yields. These higher yields were attributed to better crop growth conditions due to effective control of weeds and resultant improved growth, yield parameters and yields. These less crop-weed competition and favourable growing environments have led to more energy returns per unit of energy input used, hence was reflected in terms of higher net energy returns, energy use efficiency, energy productivity and lower specific energy. Whereas, lowest input energy revealed under unweeded check was because of no weed control activity/operations undertook in the treatment. Thus, due to no weed control, it has witnessed lower pod and haulm yields (846 and 1333 kg/ha, respectively). These outcomes are further supported by Nagarjun *et al.* (2019) reported higher input energy, output energy, net energy returns, energy productivity and lower specific energy under hand weeding at 20, 40 and 60 DAS followed by other herbicidal and unweeded check treatments. These findings are further proponented by Malhi *et al.* (2021).

Effect on phytotoxicity of groundnut and residual effects

A perusal of data in Table 6 indicated that among different herbicides used for the management of weeds in groundnut, sulfentrazone 28 + clomazone 30 WP @ 350 + 375 g/ha (PE) and fluthiacet-methyl 10.3 EC @13.6 g/ha (POE) have recorded visual phytotoxicity symptoms. Wherein, sulfentrazone 28 + clomazone 30 WP @ 350 +

375 g/ha (PE) treatment indicated phytotoxicity symptoms scores of 2, 6 and 7 at 7, 14 and 28 days after application of herbicides, respectively due to phytotoxicity symptoms appeared on groundnut like stunting and discolouration in initial stages followed by severe injury with the stand loss. Fluthiacet- methyl 10.3 EC @13.6 g/ha (POE) has also recorded phytotoxicity symptoms scores of 1, 2 and 3 at 7, 14 and 28 days after application of herbicides due to symptoms observed on groundnut crop like slight discolouration and stunting which were not persistent. Whereas, all the other herbicides have not caused any phytotoxicity symptoms on groundnut. These outcomes are further supported by Fisher and Smith (2001) who observed stunting of flue cured tobacco in pre-plant incorporated sulfentrazone and clomazone. Reddy *et al.* (2014) also observed 9-38 % injury in sorghum crop at four days after treatment with fluthiacet-methyl. Further these findings were also supported by Dan *et al*. (2010) and Petruic *et al*. (2016).

The residual effect of various herbicides was studied by sowing wheat, mustard and chickpea seeds in all the treated undisturbed plots in the next season (*Rabi* 2021) and the data on plant population per row length at 15 DAS in net plot was recorded and the same is illustrated in Table 6. The data revealed that there was no significant difference in the plant population per row length at 15 DAS, which indicates no residual toxic effect on the germination and plant stand of succeeding wheat, mustard and chickpea crops. Results clearly indicated that no much residues caused impact on germination of succeeding crops *i.e.,* wheat, mustard and chickpea. The similar consequences were also witnessed by Mehriya *et al.* (2020) who observed no residual effect of different weed management practices or application of different herbicides applied to groundnut on succeeding wheat crop.

Conclusion

The current investigation concludes that, depending on the availability of labor or herbicides for the effective weed management in groundnut, higher pod yield and haulm yield in kharif groundnut can be secured either by two hand weedings at 20 and 40 DAS or interculturing and hand weeding at 15 and 30 DAS or post-emergence application of sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165+80 g/ha or imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha.

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Table 1: Major weed flora (No./m^2) at 30 DAS in groundnut as influenced by weed management practices

Treatments	Sedge	Grasses				BLW							GT
	Cr	**Cd**	**Dm**	**Ds**	**Dag**	**Po**	**Be**	**Tt**	**La**	**Da**	**Cb**	**Av**	
T_1	12.88	6.25	4.00	3.23	2.40	5.48	4.11	2.74	1.37	6.84	1.10	2.74	56.88
T_2	9.00	6.00	3.81	3.00	2.16	2.40	1.80	1.20	0.60	3.00	0.48	1.20	36.25
T_3	7.63	6.10	4.00	3.10	2.20	2.23	1.67	1.11	0.56	2.78	0.45	1.11	34.88
T_4	20.13	15.83	9.78	7.96	6.02	11.33	7.74	5.16	2.58	13.91	2.50	5.16	113.38
T_5	19.50	16.25	10.52	7.50	6.40	12.81	8.86	5.91	2.95	15.77	2.36	5.91	121.94
T_6	19.00	18.75	11.33	9.34	7.12	11.50	8.41	5.25	2.63	13.13	2.10	5.25	120.88
T_7	18.88	15.20	8.63	7.10	5.13	12.08	8.31	5.54	2.77	13.84	2.22	5.54	112.75
T_8	6.13	5.30	3.52	2.84	2.01	1.88	1.41	0.94	0.47	2.34	0.38	0.94	30.00
T_9	5.88	5.03	3.12	2.32	1.62	1.75	1.31	0.88	0.44	2.19	0.35	0.88	27.75
T_{10}	19.00	17.09	10.46	8.18	6.21	10.90	8.18	5.45	2.73	13.63	2.18	5.45	118.13

Data is statistically not analyzed, averaged over 2 spots/plot and over four replications
Total weed count includes the density of minor weeds which are not included in the table

T_1: Pendimethalin 38.7 CS @ 1000 g/ha (PE), **T_2:** Diclosulam 84 WDG @ 22 g/ha (PE), **T_3**: Sulfentrazone 28 + clomazone 30 WP @ 350 + 375 g/ha (PE), **T_4**: Sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (PoE), **T_5**: Imazethapyr 10 SL @ 100 g/ha (PoE), **T_6**: Fluthiacet-methyl 10.3 EC @ 13.6 g/ha (PoE), **T_7**: Imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (PoE), **T_8**: Interculturing and hand weeding at 15 and 30 DAS, **T_9**: Two hand weedings at 20 and 40 DAS, **T_{10}**: Unweeded check

Sedge- Cr = *Cyperus rotundus*; **Grasses- Cd =** *Cynodon dactylon*, **Dm =** *Digitaria marginata*, **DS =** *Digitaria sanguinalis*, **Dag =** *Dactyloctenium aegyptium*; **Broad leaf weeds-Po =** *Portulaca oleracea*, **Be =** *Boerhavia erecta*, **Tt =** *Tribulus terrestris*, **La =** *Leucas aspera*, **Da =** *Digera arvensis*, **Cb =** *Commelina benghalensis*, **Av =** *Amaranthus viridis*

Table 2: Major weed flora (No./m^2) at 60 DAS in groundnut as influenced by weed management practices

Treatments	Sedge	Grasses				BLW							GT
	Cr	Cd	Dm	Ds	Dag	Po	Be	Tt	La	Da	Cb	Av	GT
T_1	13.75	12.00	5.10	8.70	2.76	1.55	3.05	4.70	1.52	9.50	3.15	7.86	76.25
T_2	13.63	12.05	6.00	9.00	2.95	1.35	2.80	4.40	1.25	8.08	2.85	7.56	74.25
T_3	13.50	11.76	5.85	8.78	2.70	1.30	2.46	4.40	1.28	8.40	2.88	6.44	72.75
T_4	6.38	5.45	3.05	4.06	1.10	0.70	1.45	2.30	0.64	4.50	1.41	3.58	37.50
T_5	11.00	9.70	4.85	7.28	2.43	1.22	2.20	3.09	1.15	6.68	2.13	5.25	60.25
T_6	20.25	16.80	8.50	12.98	4.12	2.50	5.25	8.13	2.40	17.05	5.25	14.08	121.25
T_7	8.50	7.75	3.73	5.50	1.62	0.79	1.50	2.46	0.80	4.83	1.48	4.06	45.88
T_8	6.50	5.10	2.80	4.12	1.18	0.70	1.35	1.88	0.53	3.95	1.20	3.15	36.25
T_9	5.88	5.00	2.53	4.10	1.24	0.54	1.09	1.58	0.60	3.42	1.11	2.92	33.38
T_{10}	44.88	24.00	12.20	18.30	6.20	4.00	6.63	12.20	4.28	24.90	7.89	20.58	195.20

Data is statistically not analyzed, averaged over 2 spots/plot and over four replications
Total weed count includes the density of minor weeds which are not included in the table

T_1: Pendimethalin 38.7 CS @ 1000 g/ha (PE), **T_2**: Diclosulam 84 WDG @ 22 g/ha (PE), **T_3**: Sulfentrazone 28 + clomazone 30 WP @ 350 + 375 g/ha (PE), **T_4**: Sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (PoE), **T_5**: Imazethapyr 10 SL @ 100 g/ha (PoE), **T_6**: Fluthiacet-methyl 10.3 EC @ 13.6 g/ha (PoE), **T_7**: Imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (PoE), **T_8**:Interculturing and hand weeding at 15 and 30 DAS, **T_9**: Two hand weedings at 20 and 40 DAS, **T_{10}**: Unweeded check

Sedge- Cr = *Cyperus rotundus*; **Grasses- Cd =** *Cynodon dactylon*, **Dm =** *Digitaria marginata*, **DS =** *Digitaria sanguinalis*, **Dag =** *Dactyloctenium aegyptium*; **Broad leaf weeds-Po =** *Portulaca oleracea*, **Be =** *Boerhavia erecta*, **Tt =** *Tribulus terrestris*, **La =** *Leucas aspera*, **Da =** *Digera arvensis*, **Cb =** *Commelina benghalensis*, **Av =** *Amaranthus viridis*

Table 3: Major weed flora (No./m^2) at harvest in groundnut as influenced by weed management practices

Treatments	Sedge	Grasses				BLW							GT
	Cr	**Cd**	**Dm**	**Ds**	**Dag**	**Po**	**Be**	**Tt**	**La**	**Da**	**Cb**	**Av**	
T_1	10.88	10.11	4.42	4.01	3.00	2.40	2.88	3.40	1.16	5.78	2.91	4.62	59.75
T_2	10.38	10.00	4.45	4.22	3.10	2.05	2.51	3.80	1.15	4.32	2.48	4.40	56.63
T_3	10.00	9.66	4.20	4.12	3.17	2.15	2.48	3.53	1.06	5.11	2.41	3.62	54.64
T_4	4.88	4.06	2.06	1.92	1.29	1.00	1.41	1.75	0.54	2.10	1.25	2.01	27.00
T_5	8.61	7.90	3.40	3.60	2.40	1.61	2.10	2.78	0.79	3.97	1.99	3.15	45.24
T_6	16.38	14.22	7.20	5.90	4.00	4.22	4.61	7.25	2.08	9.80	5.13	7.70	92.63
T_7	6.25	6.07	2.52	2.68	2.12	1.20	1.50	2.10	0.54	2.84	1.42	2.32	33.74
T_8	4.75	4.50	2.00	2.10	1.38	1.04	1.35	1.70	0.52	2.35	1.15	1.42	25.63
T_9	4.25	4.60	2.00	1.88	1.35	0.89	1.20	1.47	0.39	2.15	1.03	1.68	24.00
T_{10}	34.25	21.67	10.00	9.82	7.05	5.99	8.59	11.23	3.28	15.24	8.14	13.04	154.51

Data is statistically not analyzed, averaged over 2 spots/plot and over four replications
Total weed count includes the density of minor weeds which are not included in the table

T_1: Pendimethalin 38.7 CS @ 1000 g/ha (PE), **T_2**: Diclosulam 84 WDG @ 22 g/ha (PE), **T_3**: Sulfentrazone 28 + clomazone 30 WP @ 350 + 375 g/ha (PE), **T_4**: Sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (PoE), **T_5**: Imazethapyr 10 SL @ 100 g/ha (PoE), **T_6**: Fluthiacet-methyl 10.3 EC @ 13.6 g/ha (PoE), **T_7**: Imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (PoE), **T_8**:Interculturing and hand weeding at 15 and 30 DAS, **T_9**: Two hand weedings at 20 and 40 DAS, **T_{10}**: Unweeded check

Sedge- Cr = *Cyperus rotundus*; **Grasses- Cd =** *Cynodon dactylon*, **Dm =** *Digitaria marginata*, **DS =** *Digitaria sanguinalis*, **Dag =** *Dactyloctenium aegyptium*; **Broad leaf weeds-Po =** *Portulaca oleracea*, **Be =** *Boerhavia erecta*, **Tt =** *Tribulus terrestris*, **La =** *Leucas aspera*, **Da =** *Digera arvensis*, **Cb =** *Commelina benghalensis*, **Av =** *Amaranthus viridis*

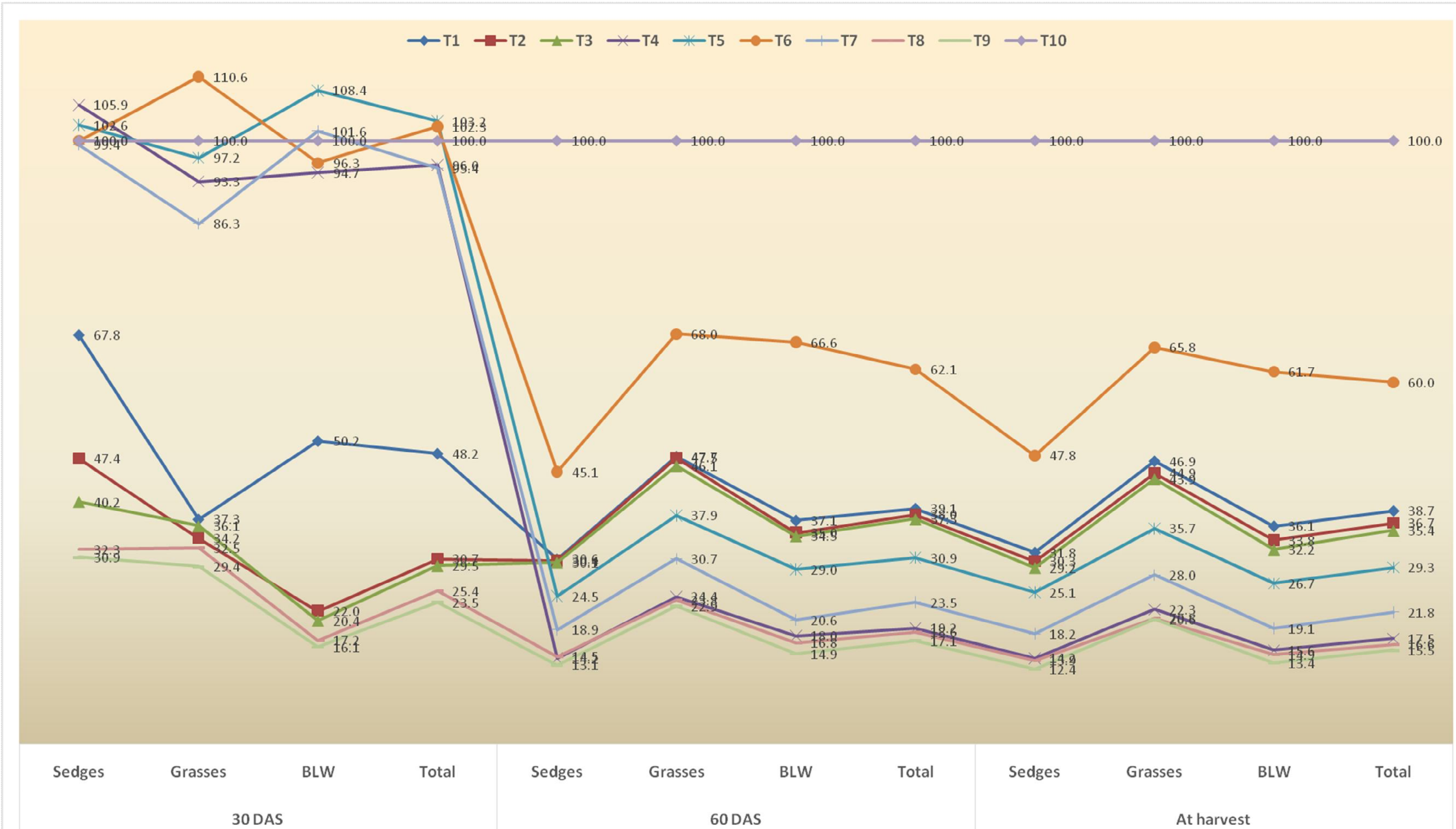

Fig. 1: Effect of weed management practices on category wise % weed density over unweeded check (100%) at different stages in groundnut

Table 4: Effect of weed management practices on various growth and yield parameters at harvest in groundnut

Treatments	Dry weight of nodules at 45 DAS (mg/plant)	Plant height (cm) at 90 DAS	At harvest										
			Total dry matter production (g/plant)	Number of filled pods per plant	Number of kernels per pod	Pod yield per plant (g)	Seed index (g)	Pod yield (kg/ha)	% yield increase over unweeded check	Haulm yield (kg/ha)	Biological yield (kg/ha)	Shelling %
T_1	60.86	37.66	31.67	16.65	1.74	7.82	38.81	1525	80.26	2387	3912	65.79
T_2	59.34	39.36	32.79	17.20	1.76	8.05	39.73	1560	84.40	2441	4001	66.08
T_3	44.44	28.20	22.66	10.25	1.77	5.20	38.67	971	14.78	1522	2494	64.85
T_4	57.12	45.61	38.39	20.40	1.75	9.32	39.77	1835	116.90	2864	4700	66.89
T_5	51.24	40.75	33.55	17.92	1.79	8.17	39.61	1619	91.37	2532	4152	66.55
T_6	47.51	31.08	25.01	13.10	1.76	6.45	39.06	1222	44.44	1913	3137	65.55
T_7	54.97	45.02	37.80	20.15	1.78	9.31	39.69	1800	112.77	2811	4612	66.19
T_8	67.78	46.26	39.51	20.90	1.75	9.47	39.59	1892	123.64	2950	4844	65.41
T_9	72.30	49.29	41.11	21.70	1.80	9.63	40.71	1980	134.04	3082	5063	67.46
T_{10}	67.49	21.47	20.16	9.38	1.73	4.40	38.57	846	0.00	1333	2181	63.98
S.Em.$\pm$	2.17	1.60	1.62	0.93	0.06	0.41	1.02	70.12		114.18	184.04	1.06
C.D. at 5%	6.29	4.65	4.71	2.70	NS	1.19	NS	203.45	NA	331.31	534.03	NS
C.V.%	7.44	8.33	10.05	11.12	7.06	10.52	5.15	9.19		9.58	9.41	3.22

Note: **T_1:** Pendimethalin 38.7 CS @ 1000 g/ha (PE), **T_2:** Diclosulam 84 WDG @ 22 g/ha (PE), **T_3**: Sulfentrazone 28 + clomazone 30 WP @ 350 + 375 g/ha (PE), **T_4**: Sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (PoE), **T_5**: Imazethapyr 10 SL @ 100 g/ha (PoE), **T_6**: Fluthiacet-methyl 10.3 EC @ 13.6 g/ha (PoE), **T_7**: Imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (PoE), **T_8**: Interculturing and hand weeding at 15 and 30 DAS, **T_9**: Two hand weedings at 20 and 40 DAS, **T_{10}**: Unweeded check

Table 5: Effect of weed management practices on economics and energetic of groundnut

Treatments	Cost of cultivation (₹ /ha)	Gross returns (₹ /ha)	Net returns (₹ /ha)	B:C ratio	Input energy (MJ/ha)	Output energy (MJ/ha)	Net energy returns (MJ/ha)	Energy use efficiency	Energy productivity (Kg/MJ)	Specific energy (MJ/kg)
T_1	54467	88185	33718	1.62	9123	52255	43132	5.73	0.17	5.98
T_2	54021	90205	36184	1.67	8864	42432	33568	4.79	0.18	5.68
T_3	56515	56160	-355	0.99	8988	33299	24310	3.70	0.11	9.26
T_4	54798	106070	51272	1.94	8963	62775	53811	7.00	0.20	4.88
T_5	53907	93610	39703	1.74	8963	55449	46486	6.19	0.18	5.54
T_6	53836	70665	16829	1.31	8875	41876	33001	4.72	0.14	7.26
T_7	54503	104055	49552	1.91	8872	61598	52726	6.94	0.20	4.93
T_8	59274	109350	50076	1.84	9058	64687	55630	7.14	0.21	4.79
T_9	61184	114410	53226	1.87	9153	67631	58478	7.39	0.22	4.62
T_{10}	51524	48965	-2559	0.95	8821	29099	20278	3.30	0.10	10.43

Note: **T_1:** Pendimethalin 38.7 CS @ 1000 g/ha (PE), **T_2:** Diclosulam 84 WDG @ 22 g/ha (PE), **T_3**: Sulfentrazone 28 + clomazone 30 WP @ 350 + 375 g/ha (PE), **T_4**: Sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (PoE), **T_5**: Imazethapyr 10 SL @ 100 g/ha (PoE), **T_6**: Fluthiacet-methyl 10.3 EC @ 13.6 g/ha (PoE), **T_7**: Imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (PoE), **T_8**: Interculturing and hand weeding at 15 and 30 DAS, **T_9**: Two hand weedings at 20 and 40 DAS, **T_{10}**: Unweeded check

Table 6: Visual phytotoxicity symptoms scores on groundnut crop and residual effect of herbicides on succeeding sown crops

Treatments	Phytotoxic symptoms scores			Plant population per five meter row length after 15 DAS		
	7 DAA	14 DAA	28 DAA	Wheat	Mustard	Chickpea
T_1: Pendimethalin 38.7 CS @ 1000 g/ha (PE)	0	0	0	233.25	50.38	49.00
T_2: Diclosulam 84 WDG @ 22 g/ha (PE)	0	0	0	231.25	51.25	49.00
T_3: Sulfentrazone 28 + clomazone 30 WP @ 350 + 375 g/ha (PE)	2	6	7	228.63	50.63	48.38
T_4: Sodium acifluorfen 16.5 + clodinafop-propargyl 8 EC @ 165 + 80 g/ha (PoE)	0	0	0	226.63	51.25	49.50
T_5: Imazethapyr 10 SL @ 100 g/ha (PoE)	0	0	0	228.25	51.50	49.25
T_6: Fluthiacet-methyl 10.3 EC @13.6 g/ha (PoE)	1	2	3	226.13	50.88	48.13
T_7: Imazethapyr 35 WG + imazamox 35 WG @ 70 g/ha (PoE)	0	0	0	227.50	49.88	49.00
T_8: Interculturing and hand weeding at 15 and 30 DAS	0	0	0	235.00	53.88	50.63
T_9: Two hand weedings at 20 and 40 DAS	0	0	0	239.50	55.00	52.13
T_{10}: Unweeded check	0	0	0	229.75	50.75	48.25
S.Em.±	NA	NA	NA	7.83	1.92	1.88
C.D. at 5%				NS	NS	NS
C.V.%				6.80	7.44	7.63

Toxicity rating: 0 = No toxicity, 10 = Highly toxic

DAA-Days after application