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RESEARCH ARTICLE

Effect of post-emergence herbicides on economic weed management and turfgrass quality characteristics of Bermuda grass Selection No. 1

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ABSTRACT

A field experiment was conducted to test the efficacy of different weed control treatments on control of turfgrass weeds in the established lawn of Bermuda grass 'Selection No. 1' at Punjab Agricultural University, Ludhiana during winter and summer seasons of 2021. The experiment was laid out in a randomized complete block design with 15 treatments *i.e.*, post-emergence application (PoE) of isoproturon 0.937 kg/ha, mesosulfuron + iodosulfuron 0.014 kg/ha, clodinafop + metribuzin 0.216 kg/ha, 2,4-D amine 0.50 kg/ha, bispyribac-sodium 0.025 kg/ha, metribuzin 0.120 kg/ha, metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha, metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha, ethoxysulfuron 0.018 kg/ha, halosulfuron 0.050 kg/ha, atrazine 1.0 kg/ha, hand weeding twice at 15 days interval and weedy check. The PoE of isoproturon 0.937 kg/ha, mesosulfuron + iodosulfuron 0.014 kg/ha, clodinafop + metribuzin 0.216 kg/ha, bispyribac-sodium 0.025 kg/ha, metribuzin 0.120 kg/ha and ethoxysulfuron 0.018 kg/ha provided complete control of *Poa annua*, a winter season weed, which was at par with hand weeding twice, whereas, in summer season, clodinafop + metribuzin 0.216 kg/ha PoE reduced the density and biomass of *Digitaria sanguinalis* and *Dactyloctenium aegyptium*. Bispyribac-sodium 0.025 kg/ha was found effective against *Dicanthium annulatum*. Metsulfuron + carfentrazone-ethyl 0.025 kg/ha PoE provided complete control of broad-leaved weeds, *viz. Gnaphalium purpureum*, *Oxalis corniculata*, *Desmodium triflorum*, *Coronopus didymus* in winter season and *Boerhavia diffusa* and *Alysicarpus vaginalis* in summer season. Halosulfuron 0.050 kg/ha PoE effectively controlled *Cyperus rotundus* upto 45 days after spray (DAS) during winter season. Metsulfuron + carfentrazone-ethyl 0.025 kg/ha PoE recorded highest weed control efficiency (WCE) (72.9 %) during winter, whereas in summer clodinafop + metribuzin 0.216 kg/ha PoE recorded highest WCE. Sward height and dry biomass of turfgrass were found negatively correlated with the weed biomass in both of seasons. Phyto-toxicity was observed with clodinafop + metribuzin (0.216 kg/ha) PoE, however, the grass recovered after 35 DAS in winter season.

Keywords: Economics, Herbicides, Turfgrass, Weed management

INTRODUCTION

A lawn is an indispensable feature of a residential landscape with a considerably greater proportion of space relative to other garden features. A weed free lawn is valued for providing aesthetic and functional utility in a residential, institutional, public and several other amenity area. In India, the turfgrass industry is being regarded as a consolidated sector of ornamental horticulture, spanning more than 30,000 acres under different turf grasses at recreational facilities, residential colonies and sports grounds.

Bermuda grass [*Cynodon dactylon* (L.) Pers.] is the most widely planted amenity turfgrass appreciated for its several desirable traits, *viz.* drought resistance, trespassing tolerance, disease resistance and relatively better recuperative potential (Zhang *et al.* 2017). Lawns are generally mowed and maintained at short height (not more than 3-5 cm) to encourage dense growth of lateral stolons to form a lush green mat, that offers several recreational (adds aesthetics to a landscape and provide comfortable sitting) and ecological services (reduces rainwater runoff, prevents soil erosion, regulates temperature, sequesters carbon and trap particulate matter). However, it has become a common observation to sight weed encroachment in the improved strain (Selection No.1) of Bermuda grass, that considerably affects the aesthetics of lawn (Siddappa *et al.* 2016). Infestation of weeds in turfgrass not only competes for moisture, nutrients, sunlight and space but also harbor several insects and fungal pathogens rendering it unsuitable for active or passive recreation (Busey

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2003). It has also been observed that altering certain agronomic practices to reduce the competitiveness of one weed may cause other weed species to resurge or may exhibit a shift in weed flora due to periodic application of pre-emergence and post-emergence herbicide application (Ramachandra *et al.* 2014).

The weed management in lawn is being undertaken following physical or mechanical removal of weeds, spray of herbicides and adopting an integrated seasonal approach for holistic control of weed growth. Although the mechanical ways to manage the weeds from lawn is generally advocated, but it is labor-intensive, incur higher costs, cause soil compaction due to repeated trampling and trespassing and often a times unpractical to rough out weeds in extensively planted lawns. It is a mandatory cultural practice to undertake hand weeding 2-3 times in a newly planted lawn for its rapid establishment to encourage dense growth and suppress the weed emergence (Siddappa *et al.* 2015a). Turfgrass landscapes rely on application of different post-emergence herbicides and is believed to be a practically feasible alternative especially in extensively planted areas (Doughlas *et al.* 2005). These herbicides gradually percolate in the soil by rain or irrigation and thereafter uptake by the roots and shoots of weeds. The residual activity of herbicides in soil depends upon the herbicidal group and rate of application (Sondhia 2014). Depending upon the mode of action, post-emergence herbicides may act as a direct contact herbicide or may get translocated through conducting tissues of weed plants through the xylem and phloem and finally reach the target site where these interfere with plant physio-chemical processes, ultimately causing their mortality and suppress the weed density. Therefore, it is pertinent to address the issue of weed infestation in turfgrass to ensure a healthy, lush green and weed-free lawn. Due to the omnipresent nature of the weeds, an integrated approach to weed control along with application of herbicides is necessary to curtail the spread of weeds and maintain the quality of turfgrass (Uddin *et al.* 2012). The objective of this study was to test the efficacy of different weed control treatments on turfgrass weeds and to assess their potential effects on turfgrass quality in the established lawn of Bermuda grass ‘Selection no. 1.

MATERIALS AND METHODS

The experiment was conducted at Punjab Agricultural University, Ludhiana over well-established lawn of Bermuda grass var. ‘Selection no. 1’. The experimental site was selected based on the representation of maximum diversity of weed species in both winter and summer season. The site geographically tagged at 30°56' N latitude, 75°52' E longitude is a representive of the Indo-gangetic alluvial plain at an altitude of 247 m above mean sea. The climate of experimental site was sub-tropical characterized by semi-arid climate with hot summers and severe winters receiving mean annual rainfall of 700 mm. The mean maximum temperature above 45° C is common during summer months (May-June) and during winter months (December-January) the temperature falls below 4° C occasionally. The experiment was laid out in randomized complete block design (RBD) with 15 treatments replicated thrice. The treatments comprised of post-emergence application (PoE) of isoproturon 0.937 kg/ha, mesosulfuron + iodosulfuron 0.014 kg/ha, clodinafop + metribuzin 0.216 kg/ha, 2,4-D amine 0.50 kg/ha, bispyribac-sodium 0.025 kg/ha, metribuzin 0.120 kg/ha , metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha, metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha, ethoxysulfuron 0.018 kg/ha, halosulfuron 0.050 kg/ha, atrazine 1.0 kg/ha, hand weeding twice (at 15 days interval) and weedy check. The soil texture of the experimental site was sandy loam, slightly alkaline in soil reaction (pH 8.0) and lower electrical conductivity (0.20 m mhos cm^{-1}). The chemical analysis of soil recorded lower organic carbon (0.21%), medium in available phosphorus (16.25 kg/ha) and available potash (172.5 kg/ha). Lawn was mowed mechanically with a lawn mower (12 inches reel width) one month before application of different weed control treatments and later plots were irrigated at fifteen days interval. The PoE herbicides were applied on clear, sunny and calm day using knapsack sprayer attached with flat fan nozzle. As per the treatments, the required quantity of herbicide was applied by dissolving in 375 litres water/ha. Care was taken that the mowing height of grass was never kept shorter than 3.0 cm. Urea was applied as drench application at the rate 0.5 per cent at 30 days after the herbicide sprays.

Cynodon dactylon cultivar ‘Selection No. 1’, a fine strain of bermuda grass was subjected to undertake the different weed control treatments. Different weed control treatments and record of observations were made during 1 March 2021 till 30 April 2021 (for winter weed flora) and same set of treatments were repeated during 1 August 2021 till 30 September 2021 (for summer season weed flora). The observation on weed density were recorded at 15, 30 and 45 days after spray (DAS) and weed biomass was computed at 30 and 45 DAS. The qualitative turfgrass characteristics were visually assessed at 60 DAS of different herbicides. The species-wise weed density was recorded from two fixed spots in each of the treatments and was expressed as number/m^2 whereas, for weed dry biomass recorded from two random spots which was expressed as g/m^2. The weed control efficiency (WCE) of different weed control treatments was calculated to determine the percentage of weed reduction (Mani *et al.* 1976).

The sward of turfgrass was measured before mowing with a 30 cm graduated scale at 60 DAS. The scale was aligned vertical and height was measured from ground level to the tip of grass leaf blade and was expressed in cm. The colour of the turf regarded as a qualitative attribute was observed visually. The scores (1-9) were used to distinguish various hues of green colour according to the fifth edition of royal horticultural society colour chart (RHSCC). Numerical values 1-9 were coded representing different hues of green *viz*., yellow green-1, olive green-2, light green-3, gray green-4, luscious green-5, green-6, grassy green-7, dirty green-8, emerald-9. The mowed grass clippings from each of the treatment plots were sun dried for 2-3 days prior to oven drying at 55°C till the constant dry weight (expressed in g/m^2) was achieved. Visual phyto-toxicity rating was recorded at 3, 7, 10, 15 and 25 DAS of herbicidal treatments to know the extent of toxicity on bermuda grass turf. The phyto-toxicity rating was adjudged on 0 to 10 scale (Rao 1986). The phyto-toxicity rating on turfgrass was designated as 0 (no injury), 1 (slight stunting injury or discoloration), 2 (some stand loss, stunting or discoloration), 3 (injury more pronounced but not persistent), 4 (moderate injury, recovery possible), 5 (injury more persistent, recovery possible), 6 (near severe injury, no recovery possible), 7 (sever injury, stand loss), 8 (almost destroyed, a few plants surviving), 9 (very few plants alive), 10 (complete destruction).

The economics of different weed control treatments was calculated on the basis of prevalent market price. Cost of different PoE herbicides in Indian Rupee per hectare (INR/ha) for isoproturon = 1250, mesosulfuron + iodosulfuron = 1625, clodinafop + metribuzin = 1875, 2,4-D amine = 435, bispyribac-sodium = 1500, metribuzin = 360, metsulfuron-methyl = 300, carfentrazone-ethyl = 625, metsulfuron + carfentrazone-ethyl = 925, metsulfuron-methyl + chlorimuron-ethyl = 500 ethoxysulfuron = 1080, halosulfuron = 2240, atrazine = 720. Cost of hand weeding twice was ₹ 14720/ha (40 man-days) and cost of manpower for herbicide application was ₹ 368/ha. Square root transformation was used to transform the data for statistical inferences and improve the interpretability of the plotted graphs. All the recorded data were analyzed statistically using SPSS (IBM) statistical software Ver. 22.

RESULTS AND DISCUSSION

Winter season

The observed major weed flora, in the established bermuda turfgrass var. Selection No. 1, during winter season include *Poa annua* among grasses; *Gnaphalium purpureum*, *Oxalis corniculata*, *Desmodium triflorum*, *Coronopus didymus* among broad-leaved weeds and *Cyperus rotundus*, the sedge weed. The weed flora of well-established lawn comprises of 26.6, 60.5 and 12.7 per cent of grasses, broad-leaved weeds and sedges, respectively (**Table 1**).

Effect on weed density

The weed mortality indicates the comparative efficacy of a particular herbicide. The complete control of *Poa annua* was provided by PoE of isoproturon 0.937 kg/ha, mesosulfuron + iodosulfuron 0.014 kg/ha, clodinafop + metribuzin 0.216 kg/ha, bispyribac- sodium 0.025 kg/ha and metribuzin 0.120 kg/ha. One hand weeding at 15 DAS recorded significantly lower *P. annua* density than all other herbicide treatments and weedy check (**Table 1**). The *P. annua* density in atrazine 1.0 kg/ha was significantly lower than metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha and metsulfuron + chlorimuron-ethyl 0.004 kg/ha and weedy check which were statistically found at par with each other at 15, 30 and 45 DAS (**Table 1, 2, 3**). All the post-emergence herbicides except halosulfuron 0.050 kg/ha showed reduction in *G. purpureum* density whereas, isoproturon 0.937 kg/ha, metsulfuron 0.005 kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha and atrazine 1.0 kg/ha provided complete control at 30 and 45 DAS which was observed at par with hand weeding done twice at 15 days interval. The density of *G. purpureum* in mesosulfuron + iodosulfuron 0.014 kg/ha, clodinafop + metribuzin 0.216 kg/ha, metribuzin 0.120 g/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron + chlorimuron-ethyl 0.004 kg/ha and ethoxysulfuron 0.018 kg/ha was recorded significantly lesser than the weedy check and halosulfuron 0.050 kg/ha at 30 and 45 DAS during the winter season. Clodinafop + metribuzin 0.216 kg/ha, metribuzin 0.120 kg/ha and metsulfuron + carfentrazone-ethyl 0.025 kg/ha provided complete control of *Oxalis corniculata* at 30 DAS and the density was recorded at par with hand weeding done twice. McCurdy *et al.* (2013) also reported that metsulfuron controlled *Oxalis* spp. Mesosulfuron + iodosulfuron 0.014 kg/ha, 2,4-D 0.50 kg/ha, bispyribac-sodium 0.025 kg/ha and halosulfuron 0.050 kg/ha did not have any significant effect in checking the density of *O. corniculata* and was found at par with weedy check. All the PoE except bispyribac-sodium 0.025 kg/ha recorded significantly lesser *Desmodium triflorum* density than weedy check at 15 DAS whereas, *D. triflorum* density in metsulfuron + carfentrazone-ethyl 0.025 kg/ha was significantly lower than all other PoE and at par with hand weeding twice and had provided complete control at 30 and 45 DAS. Similar results were observed in control of *Coronopus didymus* where all the post-emergence herbicides except bispyribac-sodium 0.025 kg/ha was found effective to control *C. didymus* and had also recorded significantly lesser weed density than weedy check at 15, 30 and 45 DAS (**Table 1, 2, 3**). Herbicides clodinafop + metribuzin 0.216 kg/ha, metribuzin 0.120 kg/ha and metsulfuron + carfentrazone-ethyl 0.025 kg/ha were found very effective and provided complete control of *Coronopus didymus* and *Cyperus rotundus,* whereas their density was observed significantly lower in halosulfuron 0.050 kg/ha, ethoxysulfuron 0.018 kg/ha and 2,4-D 0.50 kg/ha as compared to all the other post-emergence herbicides and weedy check. Danilo *et al.* (2016) reported similar findings on efficacy of ethoxysulfuron in controlling the *Cyperus rotundus*. All post-emergence herbicides tested recorded best efficacy at 30 DAS against different weed flora and were found effective to curtail the

Table 1. Effect of post-emergence herbicides on weed density at 15 DAS in bermuda grass

Treatment	Dose (kg/ha)	Weed density (no./m^2)										
		Winter season						Summer season				
		Poa annua	*Gnaphalium purpureum*	*Oxalis corniculata*	*Desmodium triflorum*	*Coronopus didymus*	*Cyperus rotundus*	*Digitaria sanguinalis*	*Dichanthium annulatum*	*Dactyloctenium aegyptium*	*Boerhavia diffusa*	*Alysicarpus vaginalis*
Isoproturon	0.937	1.00^{a*} (0)	4.16^{b} (17)	7.13^{b} (50)	7.13^{bc} (50)	7.88^{e} (61)	8.23^{bc} (67)	8.25^{cd} (67)	8.25^{d} (67)	6.71^{bc} (44)	3.46^{b} (11)	7.55^{bc} (56)
Mesosulfuron + iodosulfuron	0.014	1.00^{a} (0)	4.81^{bc} (22)	9.69^{c} (94)	7.13^{bc} (50)	5.85^{bcd} (33)	7.88^{bc} (61)	8.89^{cd} (78)	6.71^{bc} (44)	6.71^{bc} (44)	3.46^{b} (11)	8.89^{c} (78)
Clodinafop + metribuzin	0.216	1.00^{a} (0)	4.16^{b} (17)	5.34^{ab} (28)	6.31^{bc} (39)	1.00^{a} (0)	6.75^{b} (44)	5.83^{b} (33)	5.83^{b} (33)	3.94^{ab} (15)	4.80^{c} (22)	8.25^{c} (67)
2,4-D amine	0.500	9.17^{b} (83)	5.34^{bc} (28)	9.46^{c} (89)	6.71^{bc} (44)	6.30^{cde} (39)	4.17^{a} (16.6)	8.25^{cd} (67)	9.49^{d} (89)	7.55^{c} (56)	3.46^{b} (11)	8.25^{c} (67)
Bispyribac-sodium	0.025	1.00^{a} (0)	5.34^{bc} (28)	9.69^{c} (94)	7.88^{cd} (61)	9.48^{f} (89)	8.15^{bc} (67)	9.49^{d} (89)	1.00^{a} (0)	5.2^{bc} (26)	4.80^{c} (22)	8.00^{c} (63)
Metribuzin	0.120	1.00^{a} (0)	4.16^{b} (17)	5.34^{ab} (28)	6.31^{bc} (39)	1.00^{a} (0)	7.52^{bc} (56)	7.55^{bc} (56)	8.25^{d} (67)	5.83^{bc} (33)	4.80^{c} (22)	8.25^{c} (67)
Metsulfuron	0.005	10.31^{c} (106)	4.16^{b} (17)	4.16^{a} (17)	6.74^{bc} (44)	3.47^{ab} (11)	7.88^{bc} (61)	8.25^{cd} (67)	8.89^{d} (78)	7.55^{c} (56)	3.46^{b} (11)	1.00^{a} (0)
Carfentrazone-ethyl	0.020	10.34^{c} (108)	4.16^{b} (17)	4.81^{ab} (22)	6.74^{bc} (44)	4.19^{abc} (17)	7.88^{bc} (61)	8.25^{cd} (67)	8.89^{d} (78)	6.71^{bc} (44)	3.46^{b} (11)	5.48^{ab} (29)
Metsulfuron + Carfentrazone-ethyl	0.025	10.31^{c} (106)	4.16^{b} (17)	4.16^{a} (17)	6.31^{bc} (39)	1.00^{a} (0)	8.86^{c} (78)	9.49^{d} (89)	8.89^{d} (78)	5.83^{bc} (33)	1.00^{a} (0)	1.00^{a} (0)
Metsulfuron-methyl + chlorimuron-ethyl	0.004	10.31^{c} (106)	4.16^{b} (17)	4.81^{ab} (22)	6.31^{bc} (39)	5.35^{bc} (28)	7.88^{bc} (61)	8.89^{cd} (78)	9.49^{d} (89)	7.55^{c} (56)	3.46^{b} (11)	4.79^{ab} (22)
Ethoxysulfuron	0.018	1.00^{a} (0)	4.81^{bc} (22)	10.57^{c} (111)	7.13^{bc} (50)	7.88^{e} (61)	1.00^{a} (0)	8.89^{cd} (78)	8.89^{d} (78)	7.55^{c} (56)	3.46^{b} (11)	7.55^{bc} (56)
Halosulfuron	0.050	8.22^{b} (67)	5.85^{c} (33)	9.69^{c} (94)	6.75^{bc} (44)	7.51^{de} (56)	1.00^{a} (0)	9.49^{d} (89)	8.89^{d} (78)	6.71^{bc} (44)	4.80^{c} (22)	8.25^{c} (67)
Atrazine	1.000	9.17^{b} (83)	4.81^{bc} (22)	7.13^{b} (50)	6.31^{bc} (39)	4.19^{abc} (17)	6.75^{b} (44)	8.89^{cd} (78)	8.25^{d} (67)	7.55^{c} (56)	4.80^{c} (22)	8.25^{c} (67)
Hand weeding twice (15 days interval)	-	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)
Un-weeded (control)	-	10.31^{c} (105)	5.85^{c} (33)	9.69^{c} (94)	8.82^{d} (78)	9.48^{f} (89)	8.21^{bc} (67)	9.49^{d} (89)	9.49^{d} (89)	7.55^{c} (56)	4.80^{c} (22)	8.89^{c} (78)

*Values in the parentheses are original means. Data was subjected to square root transformation ($\sqrt{x+1}$). Different alphabets indicate significant differences (p<0.05) according to Duncan's test.

weed resurgence upto 45 DAS (**Table 3**). Metsulfuron + carfentrazone-ethyl 0.025 kg/ha and metsulfuron 0.005 kg/ha alone recorded significantly lower weed density of all broad-leaved weeds compared to all other post-emergence herbicide treatments and were found as effective as hand weeding done twice at 15 days interval. Metsulfuron + carfentrazone-ethyl 0.025 kg/ha provided complete control of all broad-leaved weeds upto 45 DAS. Clodinafop + metribuzin 0.216 kg/ha followed by metribuzin 0.120 kg/ha and isoproturon 0.937 kg/ha provided effective control of grass and broad-leaved weeds and recorded significantly lower weed density compared to other post-emergence herbicide treatments.

Weed biomass

All post-emergence herbicides recorded significantly lesser total weed biomass than weedy check whereas, none of the herbicides were found as effective as hand weeding done twice at 30 and 45 DAS. Among post-emergence herbicides, the total weed biomass was weighed lowest in metsulfuron + carfentrazone-ethyl 0.025 kg/ha which was found at par with the isoproturon 0.937 kg/ha, clodinafop + metribuzin 0.216 kg/ha, metribuzin 0.120 kg/ha and atrazine 1.0 kg/ha at 45 DAS (**Table 4**).

WCE calculated at 30 and 45 DAS (**Table 4**) revealed that hand weeding twice at 15 days interval reported highest WCE (97-100%) providing complete control of all weeds except *C. rotundus*. The WCE of different post-emergence herbicides was lower than the hand weeding twice. Among the PoE herbicides, metsulfuron + carfentrazone-ethyl 0.025 kg/ha recorded highest WCE (67-72%) with 60 % of the weed density comprised of broad-leaved weeds during the winter season (**Table 1**). Metsulfuron + carfentrazone-ethyl 0.025 kg/ha showed effective control of broad-leaved weeds as reported by McAfee and Baumann (2007). The WCE of

Table 2. Effect of post-emergence herbicides on weed density at 30 DAS in bermuda grass

Treatment	Dose (kg/ha)	Weed density (no./m^2)										
		Winter season						Summer season				
		Poa annua	*Gnaphalium purpureum*	*Oxalis corniculata*	*Desmodium triflorum*	*Coronopus didymus*	*Cyperus rotundus*	*Digitaria sanguinalis*	*Dichanthium annulatum*	*Dactyloctenium aegyptium*	*Boerhavia diffusa*	*Alysicarpus vaginalis*
Isoproturon	0.937	1.00^{a*} (0)	1.00^{a} (0)	7.13^{b} (50)	7.74^{bc} (61)	5.85^{c} (33)	8.86^{bcd} (78)	8.25^{cd} (67)	9.17^{d} (83)	7.55^{bc} (56)	3.46^{b} (11)	8.25^{b} (67)
Mesosulfuron + iodosulfuron	0.014	1.00^{a} (0)	4.81^{bc} (22)	9.69^{c} (94)	7.13^{bc} (50)	5.85^{c} (33)	8.23^{bc} (67)	8.89^{cd} (78)	7.87^{bc} (61)	7.55^{bc} (56)	3.46^{b} (11)	9.49^{c} (89)
Clodinafop + metribuzin	0.216	1.00^{a} (0)	4.16^{b} (17)	1.00^{a} (0)	6.31^{b} (39)	1.00^{a} (0)	7.52^{b} (56)	5.83^{b} (33)	5.83^{b} (33)	3.94^{ab} (15)	4.80^{c} (22)	8.89^{c} (78)
2,4-D amine	0.500	9.17^{b} (83)	5.34^{cd} (28)	9.46^{c} (89)	6.71^{bc} (44)	3.47^{ab} (11)	4.17^{a} (17)	8.25^{cd} (67)	10.34^{d} (106)	8.25^{c} (67)	3.46^{b} (11)	8.89^{c} (78)
Bispyribac-sodium	0.025	1.00^{a} (0)	5.34^{cd} (28)	9.69^{c} (94)	7.88^{bc} (61)	9.48^{e} (89)	8.86^{bcd} (78)	9.49^{d} (89)	1.00^{a} (0)	6.16^{bc} (37)	4.80^{c} (22)	8.25^{b} (67)
Metribuzin	0.120	1.00^{a} (0)	4.16^{b} (17)	1.00^{a} (0)	6.31^{b} (39)	1.00^{a} (0)	8.23^{bc} (67)	7.55^{bc} (56)	9.17^{d} (83)	6.71^{bc} (44)	4.80^{c} (22)	8.89^{c} (78)
Metsulfuron	0.005	10.31^{c} 106)	1.00^{a} (0)	4.19^{ab} (17)	6.31^{b} (39)	3.47^{ab} (11)	9.15^{cd} (83)	8.25^{cd} (67)	9.75^{d} (94)	8.25^{c} (67)	3.46^{b} (11)	1.00^{a} (0)
Carfentrazone-ethyl	0.020	10.34^{c} (108)	4.16^{b} (17)	4.81^{ab} (22)	7.13^{bc} (50)	4.19^{abc} (17)	7.52^{b} (56)	8.25^{cd} (67)	9.17^{d} (83)	7.55^{bc} (56)	3.46^{b} (11)	1.00^{a} (0)
Metsulfuron + carfentrazone-ethyl	0.025	10.31^{c} (106)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	9.15^{cd} (83)	9.49^{d} (89)	9.75^{d} (94)	6.71^{bc} (44)	1.00^{a} (0)	1.00^{a} (0)
Metsulfuron-methyl + chlorimuron-ethyl	0.004	10.31^{c} (106)	4.16^{b} (17)	4.81^{ab} (22)	6.31^{b} (39)	5.35^{bc} (28)	8.55^{bcd} (72)	8.89^{cd} (78)	10.34^{d} (106)	8.25^{c} (67)	3.46^{b} (11)	1.00^{a} (0)
Ethoxysulfuron	0.018	1.00^{a} (0)	4.81^{bc} (22)	10.57^{c} (111)	7.13^{bc} (50)	7.88^{d} (61)	1.00^{a} (0)	8.89^{cd} (78)	9.75^{d} (94)	8.25^{c} (67)	3.46^{b} (11)	8.25^{b} (67)
Halosulfuron	0.050	8.22^{b} (67)	5.85^{d} (33)	9.69^{c} (94)	6.75^{bc} (44)	7.51^{d} (56)	1.00^{a} (0)	9.49^{d} (89)	9.75^{d} (94)	7.55^{bc} (56)	4.80^{c} (22)	8.89^{c} (78)
Atrazine	1.000	9.17^{b} (83)	1.00^{a} (0)	7.13^{b} (50)	7.13^{bc} (50)	4.19^{abc} (17)	7.52^{b} (56)	8.89^{cd} (78)	9.17^{d} (83)	8.25^{c} (67)	4.80^{c} (22)	8.89^{c} (78)
Hand weeding twice (15 days interval)	-	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)
Un-weeded (control)	-	10.31^{c} (105)	5.85^{d} (33)	9.69^{c} (94)	8.82^{c} (78)	9.48^{e} (89)	9.77^{d} (94)	9.49^{d} (89)	10.34^{d} (106)	8.25^{c} (67)	4.80^{c} (22)	9.49^{c} (89)

*Values in the parentheses are original means. Data was subjected to square root transformation $(\sqrt{x+1})$. Different alphabets indicate significant differences (p<0.05) according to Duncan's test.

isoproturon 0.937 kg/ha, clodinafop + metribuzin 0.216 kg/ha and metribuzin0.120 kg/ha ranged 60-69% and these PoE herbicides effectively controlled the diverse weed flora except sedge weeds in the lawn during winter season.

Summer season

Major weed flora observed during summer season was *Digitaria sanguinalis*, *Dicanthium annulatum* and *Dactyloctenium aegyptium* among grasses; and *Boerhavia diffusa* and *Alysicarpus vaginalis* were observed among broad-leaved weeds. The density of grass and broad-leaved weeds was 70 and 30%, respectively in the well-established lawn.

Effect on weed density

Clodinafop + metribuzin 0.216 kg/ha recorded significantly lower *Digitaria sanguinalis* density as compared to other PoE herbicides and was at par with metribuzin 0.120 kg/ha (**Table 1,2** and **3**). Lowest *D. sanguinalis* density was recorded in hand weeding which was significantly lower than all the other weed control treatments. Bispyribac-sodium 0.025 kg/ha and hand weeding twice provided complete control of *Dicanthium annulatum* and its density was found significantly lower than other weed control treatments (**Table 1, 2** and **3**). Clodinafop + metribuzin 0.216 kg/ha and mesosulfuron + iodosulfuron 0.014 kg/ha were observed at par with each other and were found effective to reduce the *D. annulatum* density significantly as compared to isoproturon 0.937 kg/ha and weedy check. The lowest *Dactyloctenium aegyptium* density was recorded in hand weeding treatment which was found statistically at par with clodinafop + metribuzin 0.216 kg/ha and significantly lower than all other weed control treatments. The

Table 3. Effect of post-emergence herbicides on weed density at 45 DAS in bermuda grass

Treatment	Dose (kg/ha)	Weed density (no./m^2) – Winter season						Summer season				
		Poa annua	*Gnaphalium purpureum*	*Oxalis corniculata*	*Desmodium triflorum*	*Coronopus didymus*	*Cyperus rotundus*	*Digitaria sanguinalis*	*Dichanthium annulatum*	*Dactyloctenium aegyptium*	*Boerhavia diffusa*	*Alysicarpus vaginalis*
Isoproturon	0.937	1.00^{a*} (0)	1.00^{a} (0)	7.13^{b} (50)	9.27^{c} (89)	5.85^{c} (33)	9.77^{cd} (94)	8.89^{cde} (78)	9.49^{d} (89)	7.55^{bc} (56)	3.46^{b} (11)	8.25^{b} (67)
Mesosulfuron + iodosulfuron	0.014	1.00^{a} (0)	4.81^{bc} (22)	9.69^{c} (94)	7.88^{bc} (61)	5.85^{c} (33)	9.18^{bcd} (83)	9.49^{de} (89)	8.25^{bc} (67)	7.55^{bc} (56)	3.46^{b} (11)	9.49^{c} (89)
Clodinafop + metribuzin	0.216	1.00^{a} (0)	4.16^{b} (17)	1.00^{a} (0)	6.31^{b} (39)	1.00^{a} (0)	8.55^{bc} (72)	5.83^{b} (33)	6.32^{b} (39)	5.20^{ab} (26)	4.80^{c} (22)	8.89^{c} (78)
2,4-D amine	0.500	9.17^{b} (83)	5.34^{cd} (28)	9.46^{c} (89)	7.50^{bc} (56)	3.47^{ab} (11)	4.80^{a} (22)	8.89^{cde} (78)	10.34^{d} (106)	8.25^{c} (67)	3.46^{b} (11)	8.89^{c} (78)
Bispyribac-sodium	0.025	1.00^{a} (0)	5.34^{cd} (28)	9.69^{c} (94)	7.88^{bc} (61)	9.48^{e} (89)	9.5^{bcd} (89)	9.49^{de} (89)	1.00^{a} (0)	6.16^{bc} (37)	4.80^{c} (22)	8.25^{b} (67)
Metribuzin	0.120	1.00^{a} (0)	4.16^{b} (17)	1.00^{a} (0)	6.31^{b} (39)	1.00^{a} (0)	8.21^{b} (67)	7.55^{bc} (56)	9.49^{d} (89)	6.71^{bc} (44)	4.80^{c} (22)	8.89^{c} (78)
Metsulfuron	0.005	10.31^{c} 106)	1.00^{a} (0)	4.19^{ab} (17)	6.74^{b} (44)	3.47^{ab} (11)	10.04^{d} (100)	8.89^{cde} (78)	10.05^{d} (100)	8.25^{c} (67)	3.46^{b} (11)	1.00^{a} (0)
Carfentrazone-ethyl	0.020	10.34^{c} (108)	4.16^{b} (17)	4.81^{ab} (22)	7.13^{bc} (50)	4.19^{abc} (17)	8.21^{b} (67)	8.89^{cde} (78)	9.49^{d} (89)	7.55^{bc} (56)	3.46^{b} (11)	1.00^{a} (0)
Metsulfuron + carfentrazone-ethyl	0.025	10.31^{c} (106)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	10.04^{d} (100)	10.05^{d} (100)	10.05^{d} (100)	6.71^{bc} (44)	1.00^{a} (0)	1.00^{a} (0)
Metsulfuron-methyl + chlorimuron-ethyl	0.004	10.31^{c} (106)	4.16^{b} (17)	4.81^{ab} (22)	6.31^{b} (39)	5.35^{bc} (28)	10.04^{d} (100)	9.49^{de} (89)	10.58^{d} (111)	8.25^{c} (67)	3.46^{b} (11)	1.00^{a} (0)
Ethoxysulfuron	0.018	1.00^{a} (0)	4.81^{bc} (22)	10.57^{c} (111)	7.13^{bc} (50)	7.88^{d} (61)	4.17^{a} (17)	9.49^{de} (89)	10.05^{d} (100)	8.25^{c} (67)	3.46^{b} (11)	8.25^{b} (67)
Halosulfuron	0.050	8.22^{b} (67)	5.85^{d} (33)	9.69^{c} (94)	6.75^{b} (44)	7.51^{d} (56)	1.00^{a} (0)	10.05^{d} (100)	10.05^{d} (100)	7.55^{bc} (56)	4.80^{c} (22)	8.89^{c} (78)
Atrazine	1.000	9.17^{b} (83)	1.00^{a} (0)	7.13^{b} (50)	7.13^{bc} (50)	4.19^{abc} (17)	8.55^{bc} (72)	9.49^{de} (89)	9.49^{d} (89)	8.25^{c} (67)	4.80^{c} (22)	8.89^{c} (78)
Hand weeding twice (15 days interval)	-	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	4.17^{a} (17)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)
Un-weeded (control)	-	10.31^{c} (105)	5.85^{d} (33)	9.69^{c} (94)	9.44^{c} (89)	9.48^{e} (89)	10.04^{d} (100)	10.05^{d} (100)	10.34^{d} (106)	8.25^{c} (67)	4.80^{c} (22)	9.49^{c} (89)

Values in the parentheses are original means. Data was subjected to square root transformation ($\sqrt{x+1}$). Different alphabets indicate significant differences (p<0.05) according to Duncan's test effect of mesosulfuron + iodosulfuron 0.014 kg/ha, 2,4-D amine 0.50 kg/ha, metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha, metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha, ethoxysulfuron 0.018 kg/ha and halosulfuron 0.050 kg/ha on grass weeds was poor and was similar to weed check (**Table 1, 2** and **3**) (Siddappa *et al.* 2015a, LeStrange and Reynolds 2016). Metsulfuron + carfentrazone-ethyl 0.025 kg/ha provided complete control of *Boerhavia diffusa* upto 45 DAS and recorded significantly lower density than all other weed control treatments except hand weeding twice (McAfee and Baumann 2007). Whereas, isoproturon 0.937 kg/ha, mesosulfuron + iodosulfuron 0.014 kg/ha, 2,4-D amine 0.50 kg/ha, metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha and ethoxysulfuron 0.018 kg/ha provided significantly lower *B. diffusa* density than weedy check and were at par with each other (**Table 1, 2** and **3**). Metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha and metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha provided complete control of *Alysicarpus vaginalis* and its density was significantly lower than all other PoE treatments and at par with hand weeding twice **(Table 1, 2** and **3)**. McAfee and Baumann (2007) reported that carfentrazone and metsulfuron PoE effectively controlled broad-leaved weeds.

Weed biomass

In summer season, among PoE herbicides, lowest total dry weed biomass was recorded in clodinafop + metribuzin 0.216 kg/ha and was followed by metsulfuron + carfentrazone-ethyl 0.025 kg/ha, isoproturon 0.937 kg/ha, metribuzin 0.120 kg/ha and metsulfuron 0.005 kg/ha (**Table 4**). The grass and broad-leaved weeds density showed similar trends at 30 and 45 DAS (**Table 2** and **3**)

In summer season, clodinafop + metribuzin 0.216 kg/ha found effective in controlling grass and broad-leaved weeds (**Table 1, 2** and **3**) and reported highest WCE (33.6 %) among PoE which was followed by metsulfuron + carfentrazone-ethyl 0.025 kg/ha (31.5 %) at 45 DAS (**Table 4**).

Turfgrass characteristics

Phyto-toxicity

The phyto-toxicity rating on turfgrass was recorded periodically at 3, 7, 10, 15 and 25 DAS of different herbicides. The visual observations revealed that grasses, broad-leaved weeds and sedges were effectively controlled with the application of PoE herbicides without any visually detrimental phyto-toxic effect on the turfgrass (*Cynodon dactylon*), except in plots that were treated with clodinafop + metribuzin 0.216 kg/ha where slightly straw-coloured leaf blades were observed. However, the turf recovered effectively and regained its natural green colour at 35 days after application of clodinafop + metribuzin during winter season. However, due to greater weed density (**Table 1**) before herbicide spray during summer season, there was no observation of phytotoxicity and weeds were controlled very effectively with use of herbicide treatments.

Table 4. Effect of post-emergence herbicides on total dry biomass of weeds and weed control efficiency in bermuda grass

Treatment	Dose (kg/ha)	Total dry biomass of weeds (g/m^2)				Weed control efficiency (%)			
		Winter season		Summer season		Winter season		Summer season	
		30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	45 DAS
Isoproturon	0.937	2.94^{cd*} (7.6)	3.58^{bc} (11.8)	13.49^{bcd} (181.1)	13.97^{bcd} (194.1)	68.3	62.1	29.3	27.8
Mesosulfuron + iodosulfuron	0.014	3.60^{ef} (11.9)	3.76^{cd} (13.1)	14.47^{e} (208.4)	14.91^{f} (221.4)	50.4	58.0	18.6	17.7
Clodinafop + metribuzin	0.216	2.88^{bc} (7.3)	3.64^{bcd} (12.2)	12.91^{b} (165.6)	13.4^{b} (178.6)	69.7	60.8	35.3	33.6
2,4-D amine	0.500	3.76^{gh} (13.1)	3.89^{cde} (14.1)	15.40^{f} (236.3)	15.82^{g} (249.3)	45.5	54.8	7.7	7.3
Bispyribac-sodium	0.025	3.69^{fg} (12.6)	4.14^{ef} (16.2)	14.05^{cde} (196.4)	14.51^{def} (209.4)	47.5	48.2	23.3	22.2
Metribuzin	0.120	2.89^{bc} (7.4)	3.64^{bcd} (12.2)	13.59^{bcd} (183.8)	14.06^{bcde} (196.8)	69.4	60.7	28.2	26.8
Metsulfuron	0.005	3.38^{de} (10.4)	3.89^{cde} (14.1)	13.66^{bcd} (185.6)	14.13^{bcde} (198.6)	56.8	54.8	27.5	26.2
Carfentrazone-ethyl	0.020	3.46^{ef} (11.0)	4.01^{de} (15.1)	14.06^{cde} (196.6)	14.51^{def} (209.6)	54.3	51.6	23.2	22.1
Metsulfuron + carfentrazone-ethyl	0.025	2.74^{b} (6.5)	3.33^{b} (10.1)	13.38^{bc} (177.9)	13.61^{bc} (184.3)	72.9	67.5	30.5	31.5
Metsulfuron-methyl + chlorimuron-ethyl	0.004	3.86^{gh} (13.9)	4.35^{f} (17.9)	13.77^{cde} (188.7)	14.24^{cdef} (201.7)	42.1	42.4	26.3	25.0
Ethoxysulfuron	0.018	2.99^{cd} (7.9)	3.79^{cd} (13.4)	14.30^{de} (203.6)	14.8^{ef} (218.7)	67.1	57.1	20.5	18.9
Halosulfuron	0.050	3.74^{gh} (13.0)	4.25^{f} (17.0)	15.65^{f} (243.8)	15.98^{g} (254.4)	46.0	45.4	4.8	5.4
Atrazine	1.000	3.29^{de} (9.8)	3.69^{bcd} (12.6)	15.97^{f} (254.0)	16.37^{g} (267.0)	59.1	59.7	0.8	0.7
Hand weeding twice (15 days interval)	-	1.00^{a} (0)	1.37^{a} (0.9)	1.00^{a} (0)	2.35^{a} (4.5)	100.0	97.1	100.0	98.3
Un-weeded (control)	-	5.01^{i} (24.07)	5.67^{g} (31.18)	16.03^{f} (256.00)	16.43^{g} (269)	0.0	0.0	0.0	0.0

*Values in the parentheses are original means. Data was subjected to square root transformation ($\sqrt{x+1}$). Different alphabets indicate significant differences ($p<0.05$) according to Duncan’s test.

Sward height

The mean sward height of turfgrass was measured highest in hand weeding twice (8.4 cm) followed by plots that were treated with metsulfuron + carfentrazone-ethyl 0.025 kg/ha (8.2 cm), atrazine 1.0 kg/ha (7.7 cm), metsulfuron 0.005 kg/ha (7.6 cm), carfentrazone-ethyl 0.020 kg/ha (7.6 cm). The mean height of sward was recorded lowest (4.9 cm) in weedy check during winter season (**Figure 1**) whereas in summer, values revealed that hand weeding twice were measured significantly taller (24.1cm) sward height compared with weedy check and other herbicide treatments. Hand weeding twice and clodinafop + metribuzin 0.216 kg/ha and metsulfuron + carfentrazone-ethyl 0.025 kg/ha, recorded sward height of 21.5 cm and 21.1 cm, respectively. The greater sward height was associated with the lower weed density and biomass (**Table 1,2,3,4**).

Turfgrass colour and dry weight

The colour of turfgrass was visually assessed and designated with a numerical value on 1-9 scale at 60 DAS. The slight deviation in hue of green was noticed in all the weed control treatments, but the numerical value assessed over 1-9 colour scale was found non-significant for all the weed control treatments (data not presented). In winter season, hand weeding twice resulted in maximum dry weight of turfgrass clippings (41.74 g/m^2) followed by herbicide treated plots with metsulfuron + carfentrazone-ethyl 0.025 kg/ha (40.46 g/m^2) and isoproturon 0.937 kg/ha (40.61 g/m^2). Minimum dry weight of turfgrass clippings was recorded in un-weeded control (23.69 g/m^2) (**Figure 1**). In summer, two hand weedings resulted in maximum dry weight followed by herbicide treated plots with clodinafop + metribuzin 0.216 kg/ha. The total weed dry weight and dry weight of turfgrass clippings in lawn during both seasons was found negatively correlated at 60 DAS after mowing (**Figure 2**).

Economics

The economics of spraying of different post-emergence herbicides and manual weeding in lawn was calculated and profit margin was assessed over the conventional hand weeding practice. Manual weeding in lawn might provide nearly complete control of different types of weeds, however being more labour-intensive and time-consuming, this practice is less profitable as compared to chemical weed control (Glowicka *et al.* 2020). Metsulfuron + carfentrazone-ethyl 0.025 kg/ha provided effective control of broad-leaved weeds and recorded highest WCE. Cost saving in metsulfuron + carfentrazone-ethyl 0.025 kg/ha over hand weeding twice was INR 13427/ha, followed by metribuzin 0.120 kg/ha (INR 13992/ha) and INR 13102/ha in isoproturon 0.937 kg/ha. Application of clodinafop + metribuzin 0.216 kg/ha was found effective on grass and broad-leaved weeds with a saving of INR 12477/ha over hand weeding. Saving over hand weeding with halosulfuron 0.050 kg/ha was INR 12112/ha which performed better than other post-emergence herbicides for the control of sedges (*Cyperus rotundus*). The economics of weed control with the

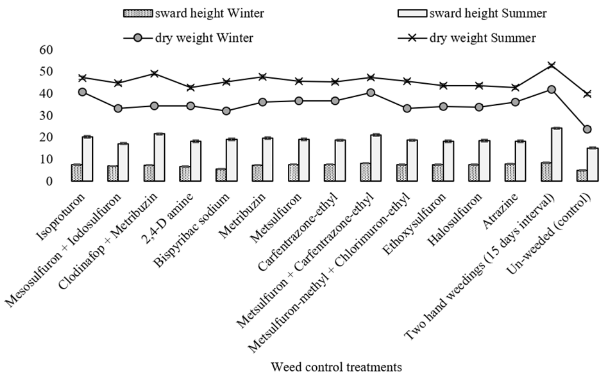

Figure 1. Effect of different weed control treatments on sward height and dry weight of turfgrass at 60 DAS

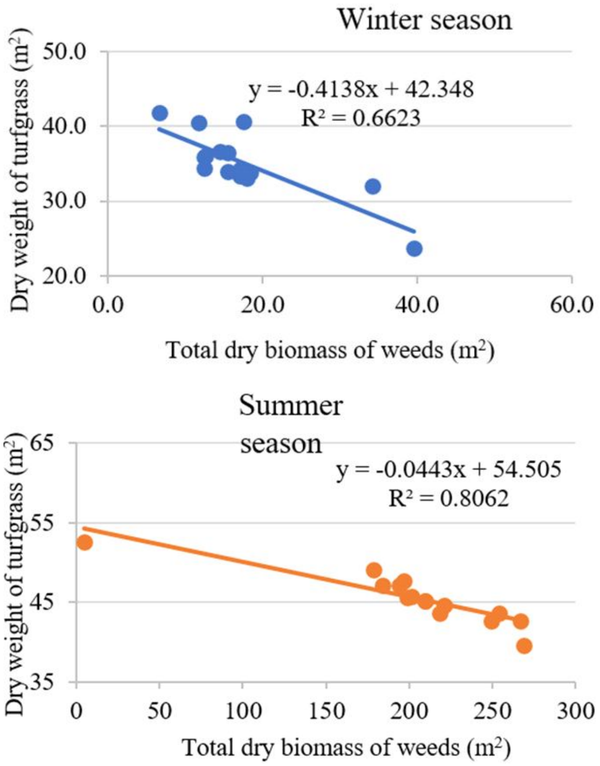

Figure 2. Correlation of weeds dry biomass (g/m^2) and dry weight (g/m^2) of turfgrass

application of herbicides proved more profitable (82.2 to 95.4 %) over manual weeding during our period of experiment in established lawn of Bermuda grass ‘Selection No. 1’. The results are in conformity with the findings of Siddappa *et al.* (2015b).

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