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Weed management in direct-seeded rice

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ABSTRACT

Rice (*Oryza sativa*), the staple food of more than half of the population of the world, is an important target to provide food security and livelihoods for millions. Direct seeding of rice (DSR) refers to the process of establishing the crop from seeds sown in the field rather than by transplanting seedling from the nursery. Before the advent of Green revolution and adoption of irrigation, rainfed rice was often broadcasted into moist soil and yields were low, variable and highly prone to weed competition. Weed spectrum and degree of infestation in rice field are often determined by rice ecosystems and establishment methods. Research evidences at different places has shown around 20-100% losses due to weeds such as *Echinochloa* spp., *Leptochloa* spp., *Cyanotis* spp., *Commelina* sp., *Digitaria* spp. and *Alternanthera* sp in DSR. Integrated weed management approach based on the critical period of crop weed competition, involving different direct and indirect control measures, has been developed and widely adopted by farmers to overcome weed problem in DSR in a sustainable way. Stale seed bed combined with herbicide (paraquat/glyphosate) and zero till results in better control. About 53% lower density was recorded due to stale seed bed. Brown manuring of *Sesbania* reduces weed population by 50%. Mulches, crop rotation and rice cultivars like *'Narender 359'* and *'Sarjoo 52'* were found better for Indo- Gangetic plains. Application of penoxsulam 25 g/ha as broad-spectrum, azimsulfuron + metsulfuron-methyl for *Cyperus* spp., pendimethalin at 1.25 kg/ha for *Echinochloa* spp. were found suitable for chemical weed management.Weed-competitive and allelopathic rice varieties, seed priming for increased weed competitiveness, higher seeding density should be considered as a management strategy.

Key words: Direct-seeded rice, Rice production systems, Weeds, Weed management, Weed shifting

Rice (*Oryza sativa* L.) is a member of poaceae family and is relished as staple food by majority of world's population. In India, rice occupied 39.16 million hectares(mha) area with a production of 85.59 million ton and average yield 2.2 t/ha (Anonymous 2013). Among the cereals, rice is the leading crop world wide (Ashraf *et al.* 2006), and more than half of the human race depend on rice for their daily sustenance (Chauhan and Johnson 2011). It is the primary source of income and employment for more than 100 million households in Asia. World's rice demand is projected to increase by 25% from 2001 to 2025 to keep pace with population growth (Maclean *et al.* 2002), and therefore, meeting ever increasing rice demand in a sustainable way with shrinking natural resources is a great challenge.

Transplanting after puddling (a process where soil is compacted to reduce water seepage) has been a major traditional method of rice establishment. Repeated puddling adversely affects soil physical properties by dismantling soil aggregates, reducing permeability in sub-surface layers, and forming hard-pans at shallow depths which make land preparation becomes difficult and requires more energy to achieve proper soil tilth for succeeding crops. Excessive pumping of water for puddling in peak summers in the North-West Indo-Gangetic Plains (IGP) resulted in declining water table. Rice production with transplanting method has been limited by a number of factors such as water scarcity, high input costs, shortage of skilled labor and suboptimal plant population. Rice seedlings are transplanted (TP) by hired skilled labour that resulted in skilled labour shortage throughout the tranplanting period which results into low plant population and eventually low rice yield. To overcome this problem, direct seeding of rice (DSR) seems only viable alternatives in rescuing farmers. Rice yield losses due to uncontrolled weed growth were least in transplanted rice (12%) but otherwise large (*cal.* 85%) where rice had been sown to dry cultivated fields or to puddled soil, rising to 98% in DSR sown without soil tillage. Weed competition reduced multiple rice yield components, and weed biomass in wet-seeded rice was six-fold greater that in rice transplanted into puddled soil and twice as much again in dry-seeded rice sown either after dry tillage or without tillage (Singh *et al.* 2011).

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The risk of greater crop yield losses due to weed competition in DSR systems than in TPR is mainly because of the absence of the seedling size differential between rice and weeds and the absence of the suppressive effect of standing water on weed emergence and growth at crop emergence time. Ramzan (2003) reported yield reduction up to 48, 53 and 74% in transplanted, direct-seeded flooded and direct-seeded aerobic rice, respectively. Aerobic rice is subject to much higher weed pressure with a broader weed spectrum than flood-irrigated rice (Balasubramanian and Hill 2002). Sunil *et al.* (2010) as stated, season-long weed competition in DSR may cause yield reduction up to 80%. Weed problem is sought to be addressed from two basic points of view: weed control and weed management. Control approach only emphasizes on reduction of weed pressure and the management approach, by contrast, focuses on keeping weed infestation at a level compatible with environmentally and economically sustainable production. However, different weed control options are available for rice. Physical control is eco-friendly but tedious and labor-intensive. Other problems include delayed weeding due to unavailability of labor damage to the rice seedlings and mistaken removal of rice seedlings. Biological control by using different bio-agents and mycoherbicides are practiced in irrigated lowland rice, but these may not be effective under aerobic soil conditions. Chemical control, on the contrary, is the most effective, economic and practical way of weed management (Hussain *et al.* 2008, Anwar *et al.* 2012a).

Status of DSR

The yield levels of DSR are comparable to the conventional tillage-transplanted rice (CT-TPR) in many studies. Some reports claim similar or even higher yields of DSR with good management practices. For instance, substantially higher grain yield was recorded in DSR (3.15 t/ha) than TPR (2.99 t/ha), which was attributed to the increased panicle number, higher 1000 kernel weight and lower sterility percentage (Sarkar *et al.* 2003). In addition to higher economic returns, DSR crops are faster and easier to plant, having shorter duration, less labour intensive, consume less water (Bhushan *et al.* 2007), conducive to mechanization (Khade *et al.* 1993), have less methane emissions (Wassmann *et al.* 2004) and hence offer an opportunity for farmers to earn from carbon credits than TPR system (Balasubramanian and Hill 2002). Dry-seeding reduces the overall water demand by reducing losses due to evaporation, leaching, percolation and amount of water needed for land preparation *etc*. (Bouman and Tuong 2001). Direct-seeding also offers the option to resolve edaphic conflicts (between rice and the subsequent non-rice crop) and enhance sustainability of the rice-based cropping system and succeeding winter crops (Farooq *et al.* 2008, Singh *et al.* 2005a) in India.

Rice production system

Rice farming is practiced in several regions and under a wide range of agro-climatic conditions. Over the centuries, naturally occurring selection pressure such as submergence, drought, and biotic stresses has widely diversified the rice ecosystem (FAO 2004). Traditionally, rice has been cultivated in flooded conditions mostly for irrigation and effective weed control (Bouman 2003). But due to shortage water, flood irrigated rice has been replaced by different less labor dependent and water saving production systems. Khush (1997) has categorized rice land ecosystems into four types. According to FAO (2007), irrigated, rainfed lowland, upland and deep water rice area have been estimated as 56.9, 30.9, 9.4 and 2.8% worldwide. In Asia, 58.6% of rice growing area is under irrigated, 32.1% under rainfed lowland, 6.7% under upland and 2.6% under deep water cultivation system. Thus, among the four rice ecosystems, irrigated rice is the main system, in terms of both area coverage and production. Irrigated rice occupies more than 50% of world rice area supplying more than 75% of global rice demand (FAO 2007). Unfortunately, this most important rice ecosystem is being increasingly endangered due to water scarcity threatening the world food security.

The promising rice technological options and crop and resource management practices designed to improve input use efficiency, save input costs and reduce the environmental footprint of irrigated rice production include site-specific nutrient management , integrated pest management and water-saving technologies such as alternate wetting and drying aerobic rice systems (FAO 2014-15).

Direct-seeding of rice refers to the process of establishing the crop from seeds sown in the field rather than by transplanting seedlings from the nursery (Farooq *et al.* 2011). Direct-seeding avoids three basic operations, namely, puddling (a process where soil is compacted to reduce water seepage), transplanting and maintaining standing water. There are three principal methods of (Table 1) establishing the direct-seeded rice (DSR): dry seeding (sowing dry seeds into dry soil), wet seeding (sowing pre - germinated seeds on wet puddle soils) and water seeding (seeds sown into standing water). Wet-DSR is primarily done under labour shortage situation, and is currently practiced in Malaysia, Thailand, Vietnam, Philippines, and Sri Lanka (Pandey and Velasco 2002, Weerakoon *et al.* 2011)

Major weed flora in DSR

Before the advent of the green revolution and adoption of irrigation, rain fed rice was often used to be broadcasted into moist soil (Pandey and Velasco 2002) and yields were low, variable, and highly prone to weed competition, as is still experienced today, particularly in upland rice (Roder *et al.* 2001). There is now evidence that water scarcity prevails in rice growing areas, and societal demands for water from the urban and commercial sectors will continue to increase. Direct-seeding of rice, in place of transplanting, provides opportunities for water savings but at the expense of the absence of the suppressive effective of standing water on weed growth. Hence, the DSR crop faces severe challenges from weeds, and effective weed management is essential for cropping of DSR.

Weed infestation is one of the major biotic constraints in rice production. Rice community is infested with diverse type of weed flora colonized by aquatic, semi-aquatic and terrestrial weeds, grown under diverse agro-climatic conditions, different cropping sequence, tillage and irrigation regimes. About 350 species have been reported as weeds of rice, of which grasses are ranked as first posing serious problem followed by sedges and broad-leaf weeds causing major losses to rice production worldwide. The predominant weed associated with DSR in Asia has been presented (Table 1)

Community composition of weeds varies according to crop establishment methods, cultural methods, crop rotation, water and soil management, location, weed control measures, climatic conditions, and inherent weed flora in the area. *Echinochloa colona* and *E. crus-galli* are the most serious weeds affecting DSR. The density of these weeds in DSR depends upon moisture condition in the field. *E. colona* requires less water, so it is more abundant in DSR. *Cyperus rotundus* and *Cynodon dactylon* may be major problems in poorly managed fields or where un-decomposed farm yard manure has been applied. The other weeds of major concern in DSR are *Paspalum* spp., *Ischaemum rugosum*, *Leptochloa chinensis*, *Digitaria sanguinalis*, *Dactyloct-enium aegyptium*, C*ommelina* spp., *Caesulia axillaris*, *Cyperus iria*, *Fimbristylis miliacea* and *Cyperus difformis.*

Table 1. Major weed species in direct-seeded rice

Scientific Name	Common Name	Family
Grasses		
Echinochloa colona	Wild rice	Poaceae
Echinochloa crus-galli	Barnyard grass	Poaceae
Eleusine indica	Goosegrass	Poaceae
Leptochloa chinensis	Sprangletop	Poaceae
Digitaria sanguinalis	Large crab grass	Poaceae
Brachiaria ramosa	Signal grass	Poaceae
Cynodon dactylon	Bermuda grass	Poaceae
Dactylotenium aegyptium	Crow foot grass	Poaceae
Broad-leaf weeds		
Alternanthera sessilis	*Khaki weed*	Amarathaceae
Ammania baccifera	*Redstem*	Lythraceae
Caesulia axillaris	Pink node flower	Asteraceae
Celosia argentia	Quail grass	Amarathance
Cleome viscosa	Cleome	Capparaceae
Commelina benghalensis	Wandering jaw	Commelinaceae
Commelina communis	Dayflower	Commelinaceae
Cyanotis axillaris	Creeping cradle	Commelinaceae
Digera arvensis	Digera kondra	Amarathaceae
Sedges		
Fimbristylis miliacea	Globefingerush	Cyperaceae
Cyperus difformis	Small flower umbrella sedge	Cyperaceae
C. iria	Flat sedge	Cyperaceae
C. rotundus	Purple nut sedge	Cyperaceae

In DSR during the first 30 days after sowing, non-grassy weeds (broad-leaf) dominated the grassy weeds and sedges, contributing more than 62% of the total weed population where *Trianthema monogyna* alone contributed more than 50 and 60% at 150 and 30 days after sowing, respectively (Table 2). At later stages, grasses dominated over non-grasses and sedges, contributing more than 90% of the total weed population at 75 DAS, at which *E. colona* alone contributed more than 80% of the total weed population at 60 DAS and beyond (Singh 2008).

Studies conducted at Pantnagar in station trail and on farm trails indicated that *C. rotundus* may pose a severe threat to direct-seeded rice system where regular flooding is absent (Singh 2008).

Losses caused due to weeds in direct-seeded rice

Weeds in DSR adversely affect yield, quality and cost of production as a result of competition for various growth factors. Extent of loss may vary depending upon cultural methods, rice cultivars, rice ecosystems, weed species association, their density and duration of competition. The greatest loss caused by the weeds, resulted from their competition with crop for growth factors, *viz*. nutrients, soil moisture, light, space, *etc* (Walia 2006). *Trianthema monogyn*a was found to grow faster than other weeds during

Table 2. Percentage composition of grassy weeds, non-grassy weeds, and sedges and their contribution (%) to dry matter production of weeds (g/m^2) at different stages (average of three crop season in unweeded plots)

Stage (DAS)	Grassy weeds		Non-grassy weeds		Sedges	
	Population	Dry matter	Population	Dry matter	Population	Dry matter
15	30.0	25.2	60.0	72.6	10.0	2.2
30	29.2	11.0	62.6	88.4	8.2	0.6
45	54.0	88.9	15.4	8.7	30.6	2.4
60	85.2	98.7	0.0	0.0	14.8	1.3
75	90.8	99.5	0.0	0.0	9.2	0.5

(Source: Singh 2008) *DAS = days after sowing

early stage due to shorter life cycle and contributed much more to the competition as compared to other weeds (Singh 2008). Globally, actual yield losses due to pests have been estimated ~ 40%, of which weeds caused the highest loss (32%) (Rao *et al*. 2007). Yield losses are largely dependent on the season, weed density, weed species, rice cultivars, growth rate, management practices and rice ecosystem. Azmi and Baki (1995) estimated that the yield loss caused by grasses (mainly *E. crus-galli*), broad-leaved weeds and sedges was 41, 28 and 10%, respectively. Weedy rice (*Oryza sativa f. spontanea*), also known as red rice, has emerged as a serious threat. It is highly competitive and causes severe rice yield losses ranging from 15% to 100% (Farooq *et al*. 2009). Weedy rice also reduces milling quality if it gets mixed with rice seeds during harvesting (Ottis *et al*. 2005). Therefore, a systematic, efficient and effective weed management depends on timing and method of land preparation, effectiveness of herbicides, relative to the dominant weed species and soil conditions at the time of application, effect of weather on weeds and effect of combining herbicides and manual weed control. In 2004, yield loss equivalent to RM90 million was estimated due to weedy rice infestation in direct-seeded rice in Malaysia (Azmi and Rezaul 2008). However, water regimes in rice fields might determine the extent of yield loss due to weed competition. On average, estimated losses from weeds in rice are around 10% of total grain yield; however, can be in the range of 30 to 90%, reduces grain quality and enhances the cost of production (Rao *et al*. 2007). In Bangladesh, rice yield losses due to weeds were estimated by 70-80% in *Au*s rice (early summer), 30-40% in transplanted *Aman* rice (late summer) and 22-36% in *Boro* rice (winter rice) (BRRI 2006).

Yield reduction due to weeds is more critical in direct-seeded rice than in transplanted rice (Karim *et al*. 2004). The competitive advantage of TPR over DSR is due to the use of 4-5 weeks old seedlings (20-30 cm tall) in TPR and also that the weeds emerging after rice transplanting are controlled by flooding after transplanting in TPR compared to DSR. In dry-seeded aerobic rice, relative yield loss caused by weeds is as high as 50-91% (Rao *et al*. 2007), while in TPR, yield loss has been estimated to be only 13% (Azmi 1992). Among the different establishment systems, yield losses are the slightly lesser in DSR (6.10 t/ha) as compared to wet-seeded rice (6.75 t/ha) and TPR (6.35 t/ha) under irrigated ecosystem. (Singh *et al*. 2006a). Dhyani *et al*. 2010 recorded lowest density and dry weight of *E.colona* in TPR as compared to DSR. Season-long weed competition in direct- seeded aerobic rice may cause yield reduction up to 80% (Sunil *et al*. 2010). In extreme cases, weed infestation may cause complete failure of aerobic rice (Jayadeva *et al.* 2011). Thus direct-seeded aerobic rice is highly vulnerable to weeds compared with other rice ecosystems (Anwar *et al*. 2011).

Weed shift in DSR

Yield losses from weeds and the effectiveness of control measures depend largely upon the weed species present. Factors,which affect the composition of the weed flora include landscape position, water control, soil fertility, season, rotations and herbicide use (Moody 1996). A shift in weed populations with changing cultivation practices is thus a predictable consequence of intensification (Mortimer 1990). Direct-seeding has replaced transplanting in Asia, the annual grasses *Echinochloa colona* and *Leptochloa chinensis* have succeeded the previously dominant *Monochoria vaginalis* and *Ludwigia hyssopifolia* (Ho and Itoh 1991).

Continuous use of herbicides for the control of annual grasses shifted the dominant species from grasses to broad-leaf weeds and sedges and from annuals to perennials. The advent of direct-seeding and insufficient water supply are perceived as factors responsible for the shift in weed species dominance and diversity in rice ecosystems. Moreover, changes from traditional transplanting to direct-seeding culture (1980’s onward) resulted in drastic changes of weed flora from easy- to difficult- to-control weeds. These ecological responses in the weed flora are largely are result of habitat changes at the time of germination and establishment, associated with the absence of standing water. Extensive use of herbicides has been reported to promote shifts in the weed population (Azmi and Baki 2002). In India continuous use of grass killers such as butachlor in rice has resulted in a shift of weed flora to sedges as *C. iria*, *Scripus* spp., and *Fimbristylis* spp. (AICRP-WC-2002-03). Mortimer and Johnson 2008 during the study at Pantnagar confirmed that changing from transplanting to direct-seeding caused marked changes in the weed flora in the rice-wheat system. With direct-seeding of rice there was a rapid increase in annual grasses, *Echinocloa colona, E.crus-galli, Leptochloa chinensis*: perennial sedge *Cyperus rotundus* and certain broad-leaf weeds such as *Caesulia axillaris*. Research on farmers field showed that direct-seeding of rice is accompanied by a rapid shift in weed flora with an increase in abundance of E.*colona, E. crusgalli, Ischaemum rugosum* and *Leptochloa chinensis* and on more freely draining soil *C.rotundus* (Singh *et al.* 2006). Singh *et al.* (2013), reported that replacing transplanted rice to direct seeding rice resulted an increase in weed growth and also shift in the relative abundance of particular species. Direct seeded rice is accompanied by a rapid shift in weed flora with an increase in *E.colona, E .crusgalli* and *Ischaemum rugosum*.

Studies comparing crop establishment and weed management options at Pantnagar, over a 4-year period have shown that changing from TPR to DSR resulted in marked changes in weed populations in the rice-wheat system. In general, with diret-seeding, three annual grasses, *Echinochloa crus-galli*, *E. colona*, and *Leptochloa chinensis*, the perennial sedge *Cyperus rotundus*, and certain broad-leaf weeds such as *Commelina diffusa* and *Caesulia axillaris* increased (Fig. 1).

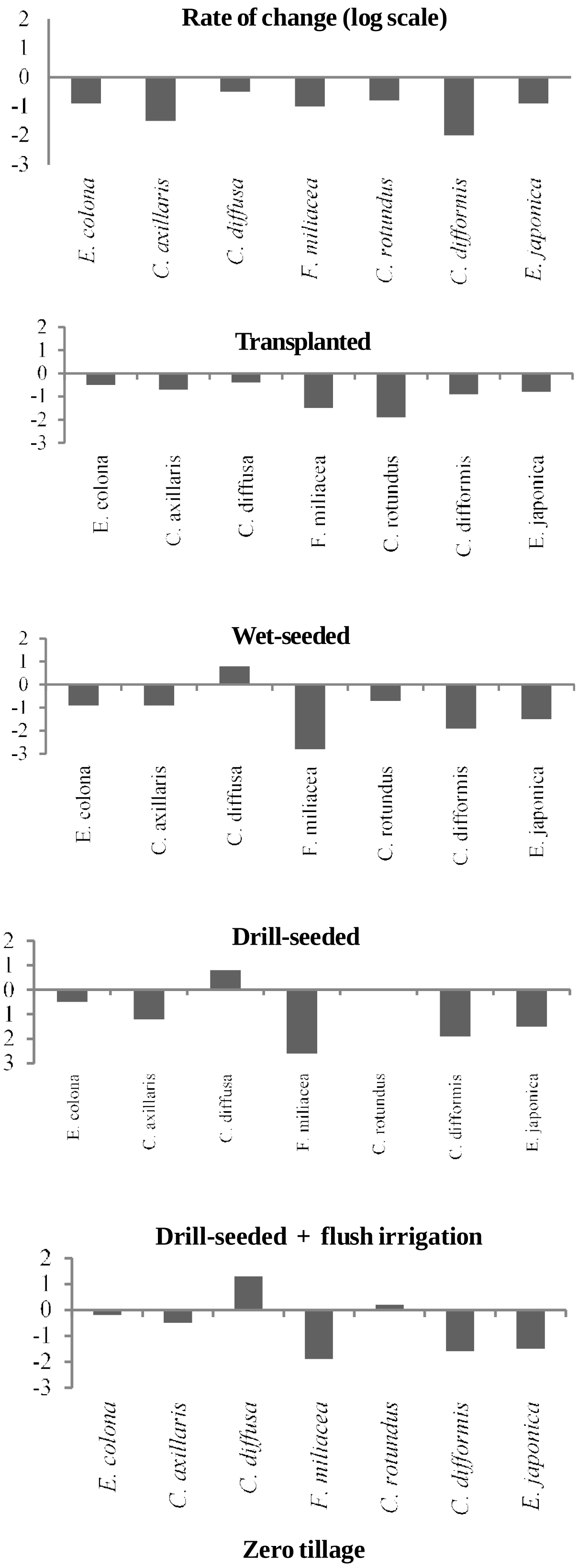

Fig. 1. Changes in abundance (mean density at 28 DAS/DAT) of weeds according to rice establishment method for species recorded in 2002. Data are the logarithm of the ratio of densities in 2004 to 2002, Pantnagar (Singh *et al.* 2008)

Weed management strategies

Multiple setbacks to weeds seem to be the best strategy to control weeds in DSR. Some of the strategies are discussed below and these should be used in conjunction rather than in isolation. Many researchers working on weed management in DSR opined that herbicide may be considered to be a viable alternative/supplement to hand weeding (Chauhan and Johnson 2011, Anwar *et al.* 2012). The other option left is cultural weed control through adoption of different agronomic practices including tillage (Rao *et al.* 2007), competitive cultivar (Zhao *et al.* 2006a), seeding density (Anwar *et al.* 2011), water management (Rao *et al.* 2007), fertilizer management (Blackshaw *et al.* 2005), seed invigoration (Ghiyasi *et al.* 2008), mulching (Singh *et al.* 2007a). Although these agronomic tools help to increase competitive ability of crop against weeds and at the same time are eco-friendly and economic, but may not provide acceptable level of weed control, especially under aerobic soil conditions, where weed pressure is very high. A single weed control approach may not be able to keep weeds below the threshold level of economic damage, and may results in shift in the weed flora, resistance development and environmental hazards. Therefore, adoption of diverse technology is essential for weed management because weed communities are highly responsive to management practices. Besides, farmers are now becoming increasingly interested in more inclusive weed management strategy to reduce herbicide dependence (Blackshaw *et al.* 2005).Therefore, while addressing environmental concern, all the methods that are ecologically and economically justifiable should be integrated in a comprehensive way, known as integrated weed management (IWM). The IWM involves the selection, integration, and implementation of effective weed control means with due consideration of economics, environmental, and sociological consequences. Concern over long-term efficacy of herbicide dependent weed management has reinforced the need for IWM. A substantial impact of IWM on rice farming has been documented by many researchers (Sunil *et al.* 2010, Jayadeva *et al.* 2011). Therefore, there is need to integrate herbicide use with other management strategies to achieve effective, long term and sustainable weed control in direct seeded rice systems. This review aims to sum up earlier work on different weed management approaches in DSR and discuss future research needs and strategies to continue to manage weeds effectively and economically, in a sustainable manner.

Preventive measures

Sowing of clean seed is perhaps the most important weed management technique in any crops. Rice seed contaminated with weeds is one of the major causes of weed infestation, especially in DSR. Rice seeds infested with weed seeds may introduce problematic weed species to a new field and increase the seed numbers in the soil weed seed bank. In many countries, for example, weedy rice or red rice spreads through the distribution of contaminated rice seeds to farmers and now this weed has become a menace because of the non availability of selective herbicides to control it. Mai *et al.* (1998) reported on average 466 weed seeds/kg rice seeds including 314 weedy rice seeds in Vietnam, which is 47 fold higher than permitted national purity level. In addition to clean crop seed, the machinery used for tillage, sowing, harvesting or threshing operations should also be cleaned before moving it from one field to another. Preventing weeds from entering an area may be easier than trying to control them once.

Cultural control

Cultural approaches play significant role to determine the competitiveness of a crop with weeds for above ground and below ground resources and hence might influence weed management (Grichar *et al.* 2004). Most cultural practices can be regarded as a means of weed suppression and an increase in their efficiency would contribute to better weed control. Moreover cultural control is also considered to be eco-friendly and when combined with herbicides or other methods can result in better weed management.

Stale seed bed: The stale seed bed technique is an important cultural practice that can be used before any crop to reduce the weed seed bank. In this technique, after pre-sowing irrigation, fields are left as such and weeds are allowed to germinate and thereafter are killed through cultivation or with the use of non-selective herbicide (e.g., paraquat or glyphosate) application or shallow tillage. This technique is quite effective in DSR, especially for controlling weeds such as *C. rotundus,* weedy rice, and volunteer rice seedlings. Herbicides may destroy weeds without disturbing the soil, which would be advantageous and hence reducing the possibilities of bringing new seeds to the upper soil surface. The rice seeds should be sown with minimum soil disturbance after destroying the emerged weeds. The use of zero-till-ferti-seed drills may be useful to serve this purpose. Singh *et al*. 2009 reported 53% lower density in Dry- DSR after a stale seed bed than without this practice. Stale seedbed combined with herbicide (paraquat) and zero-till results in better weed control because of low seed dormancy of weeds and their inability to emerge from a depth >1 cm (Chauhan and Johnson 2010). The success of stale seed bed de-pends on several factors: (a):- method of seed bed preparation (b):- method of killing emergence weed (c):- weed species (d):- duration of stale seed bed and (e):- environmental conditions.

Tillage: Tillage is an important cultural practice to reduce the incidence of perennial weeds. Dry-seeded rice can be sown under zero till or reduced till conditions or thorough land preparation. The importance of thorough land preparation to minimize weed pressure is well recognized. Tillage can affect weed community through the changes in weed seed distribution in the soil. Primary tillage can reduce annual weed populations, especially when planting is delayed to allow weed seeds to emerge before final tillage. While shallow tillage before crop emergence and post plant tillage after crop establishment help remove annual weeds and inhibit the growth of perennial weeds. On the other hand, zero tillage favors weed infestation. Conservation tillage has been criticized particularly in relation to lower yields and perennial weed problems which results in an increase in herbicide application (Singh *et al.* 2011). Zero tillage DSR had more equivalent yield than DSR CT. Presence of crop residue in tillage practices increases weed suppression and tillage in darkness can delay and reduce the emergence of certain weed species.

The rice yield was statistically at par in case of zero tillage (ZT) when compared with the conventional tillage (CT) system in DSR (Bhattacharayya *et al.* 2006). It was further reported that ZT may be adopted as resource conservation technology (RCT) and producing good crop yield. Another study reported that DSR with conventional seeding (in the prepared field) or rotavator (RT) seeding was better than ZT seeding. However, soil quality parameters (*viz.* soil organic carbon (SOC) concentration, bulk density and moisture content) were significantly better under conservation tillage (ZT and RT) than CT (Bazaya *et al.* 2009). CT recorded significantly higher yield than ZT (Bhatacharayya *et al.* 2006). Another study recorded that the direct-seeded ZT gave at par yield as compared with transplanted (TP) rice (Singh *et al.* 2008). ZT rice after spray of glyphosate 0.5 kg/ha gave significantly higher yield over the other methods of establishment.

Brown manuring (*Sesbania* co-culture): "Brown manuring" practice involves seeding of rice and *Sesbania* crops together and killing the *Sesbania* crop 25-30 days after sowing (DAS) by application of 2,4-D-ester at 0.40-0.50 kg/ha. This will also help in meeting early N requirement of the crops and avoid early nitrogen and moisture stress (CIMMYT 2010, Gurjeet *et al.* 2013). Methane gas emission and global warming potential was maximum under conventional- TPR and emission of N_2O was maximum under DSR crop with conservation practice of brown manuring as the addition of organic matter to soil increased the decomposition rate, which resulted in higher emission of GHGs (Bhatia *et al.* 2011).

Water management: In rice cropping, water constitutes a powerful selective agent for weed management (Mortimer and Hill 1999). Water is the "best herbicide". Every weed species has an optimum soil moisture level, below or above which its growth is hampered, and therefore time, depth and duration of flooding could play an important role in suppressing weeds. Water depth can be used to control many weeds, but some species are relatively unaffected by water depth. Good water management together with chemical weed control offers an unusual opportunity for conserving moisture and lowering the cost of rice production (Rao *et al.* 2007). The importance of water management for controlling weeds in rice is well-known but water management is yet to achieve its full potential.

The effect of rice crop establishment methods on infiltration rate was recorded at PDCSR, Modipuram (Uttar Pradesh) during 2004. The infiltration rates of the three transplanting methods (irrespective of puddling) were almost the same (31-34 mm/day). The infiltration rate of direct-seeded plots in a dry bed (75 mm/day) was higher than in drum-seeded plots in a wet bed (65 mm/day).

If germplasms are developed for rice, which cause very rapid growth than water level can be increased initially to control weeds. The extent to which genes that ensure rapid establishment and submergence tolerance can be exploited for germplasm adapted for direct seeding remains a pressing research issue.

Fertilizer management: Fertilization affects weed growth in rice fields. Manipulation of crop fertilization is a promising approach to reduce weed infestation and may contr-ibute to long-term weed management (Blackshaw *et al.* 2004). Fertilizer management should be aimed at maximizing nutrient uptake by crop and minimizing nutrient availability to weeds. Nitrogen fertilizer has been reported to break weed seed dormancy and influence weed densities. The time of nitrogen application also influences weed growth. Many weed species consume high amount of N and; thus, reduces N availability for crops. The proper mana-gement of N in DSR reduces the weed competition, and hence should be applied as per the requirement of the crop. The application of excess amount of N fertilizer, on the other hand, encourages weed growth and reduces yield. Recently, Mahajan and Timsina (2011) reported that when weeds were controlled, rice crop responded to higher amount of N application but under weedy and partially-weedy conditions, grain yield reduced drastically with higher amount of N fertilization. With inadequate weed control, it is best not to apply N or to apply N at low amounts.

Weed-competitive cultivar: Rice cultivar with strong weed competitiveness is deemed to be a low-cost safe tool for weed management (Gibson and Fischer 2004). Short stature, early maturing, erect rice cultivars are less competitive with weeds than cultivars that are tall and have fast and vigorus early vegetative growth, a vigorus root system, high tillering and drooping leaves. It has been observed that early maturing rice cultivars and rice hybrids also have a smothering effect on weeds due to improved vigour and having the tendency of early canopy cover (Mahajan *et al.* 2011). Competitive rice cultivar effectively supp-ressed the infestation of *Echinochloa* spp. and helped reduce herbicide dependency (Gibson *et al.* 2001).

At present, no varieties are available that are targeted for alternate tillage and establishment methods, especially in unpuddled or ZT soil conditions with direct-seeding (Dry-DSR) in Asia (Fukai 2002, Watanabe *et al.* 1997). Direct dry-seeded rice requires specially bred cultivars having good mechanical strength in the coleoptiles to facilitate early emergence of the seedlings under crust conditions (generally formed after light rains), early seedling vigour for weed competitiveness (Jannink *et al.* 2000, Zhao *et al.* 2006a), efficient root system for anchorage and to tap soil moisture from lower layers in peak evaporative demands (Clark *et al.* 2000. Pantuwan *et al.* 2002) and yield stability over planting times are desirable traits for DSR.

Seeding rate: High seeding rates are used in DSR systems. Farmers used high seed rate to compensate for poor seed quality and poor crop emergence as they use their own stored seeds and compensate for losses due to rodents, birds, insects *etc*. In addition, the use of high seed rates can also help in suppressing weed growth. Low plant density and high gaps encourage the growth of weeds, and in many cultivars, result in less uniform ripening and poor grain quality. On the other hand, very high plant stand should be avoided because it tends to have less productive tillers, increases lodging, prevents the full benefit of nitrogen application, and increases the chances of rat damage. A study was conducted in the Philippines and India in 2008 and 2009 to assess the relations of seeding rate (15-125 kg/ha) of hybrid and inbred varieties to crop and weed growth in aerobic rice. Plant densities, tillers and biomass of rice increased linearly with increased in seeding rates under both weedy and weed free environments. Weed biomass decreased linearly with increasing seed rate from 15 to 125 kg/ha. Panicles and grain yield of rice in competition with weeds increased in a quadratic relation with increased seeding rates at both locations: however, the response was flat in the weed free plots. A quadratic model predicted that seeding rates of 48-80 kg/ha for the inbred varieties and 47-67 kg/ha for the hybrid varieties were needed to achieve maximum grain yield when grown in the absence of weeds, while rates of 95-125 kg seed/ha for the inbred varieties and 83-92 kg seed/ha for the hybrid varieties were needed to achieve maximum yields in competition with weeds. On the basis of these results, seeding rates > 80 kg/ha are advis-able where there are risks of severe weed comp-etition. Such high seeding rates may be prohibitive when using expensive seed, and maximum yields are not the only consideration for developing recommendations for optimizing economic returns for farmers. (Chauhan *et al.* 2011). Higher seeding rates would be beneficial if no weed control is planned or if only partial weed control is expected. However, it is not necessary to use high seeding rates to suppress weeds in DSR if effective herbicides are used.

Crop rotation: Crop rotation can be used to minimize crop damage from weeds. Rotating crops having dissimilar life cycles or cultural conditions (so as to break the cycles of the weeds) is among the, most effective of all weed control methods. Intensive cropping systems can increase the competitive ability of the crops, thereby reducing the weed pressure. The direct-seeded CT plots had similar grain yield as the direct-seeded ZT plots of rice and wheat after 4 years of cropping (Bhattacharyya *et al.*, 2008). However, the ZT practice had lower cultivation costs and crops under ZT could be sown earlier than CT (Singh *et al.* 2002). However, the significantly same grain, straw and biological yield was recorded with ZT in standing stubbles after removal of loose straw, CT with and without mulching (Singh 2010). Sharma *et al.* (1995) observed that the higher total productivity of 9.3 t/ha was recorded under direct-seeded, puddled condition, followed by transplanting (9.1 t/ha) and direct-seeded, dry condition (8.99 t/ha). Owing to substantial saving of labour under direct-seeded, puddle condition higher net returns of ₹14741/ha was obtained compared with ₹ 498/ha under direct-seeded, dry condition and ₹12981/ha under TPR.

In North India, rice wheat is a dominant system and similar type of crops the rotation also allows similar weeds to flourish. It is difficult however, to replace crops of rotation due to food habits, market, support price etc. It is possible however to diversify this system especially with technologies such as DSR and zero tilled wheat. These technologies give additional one month in between rice and wheat crops. Growing short duration potato, vegetable or legumes in rice-wheat system may ameliorate soil fertility and break the cycle of weed and disease complex as against continuous rice-wheat system over extended period. Weed problem in rice has been observed to be reduced by planting cowpea during dry season, rather than keeping the field fallow. Planting mungbean in dry season in Northern India also reduced weed growth and weeding time and increased herbicide performance (Mahajan *et al*. 2012). This practice is more effective in suppressing weeds, therefore if combined with pre-emergence application of pendimethalin, its performance in suppressing weeds increases.

Residue management and co culture: Crop residue present on soil surface not only improves soil and moisture conservation but can also influence weed seedling emergence and weed growth. However, the response of weeds to residue depends on many factors, including the quantity and position of weed seeds relative to the residue, and the biology of the weed species. In some areas, where time is sufficient between two crops, legume crops such as *Sesbania* and mungbean can be used to reduce the weed population. These crops are killed by using nonselective herbicides and their residue may not only help in suppressing weed emergence but also add fertility to the soil. *Sesbania* co-culture technology can reduce the weed population by nearly half without any adverse effect on rice yield (Dhyani *et al*. 2007). It involves seeding rice and *Sesbania* crops together and then killing *Sesbania* with 2, 4-D ester about 25-30 DAS. *Sesbania* grows rapidly and suppresses weed. This practice is found more effective in suppressing weeds therefore if combined with pre-emergence application of pendimethalin, its performance in suppressing weeds increases. In yet another study (Singh and Singh 2007), *Sesbania* co-culture reduced broad-leaf and grass weed density by 76-83% and 20-33%, respectively, and total weed biomass by 37-80% compared with sole rice crop. *Sesbania* knocked down by the application 2, 4-D 0.5 kg/ha at 30 DAS was found more effective towards the density of weeds than application of pretilachlor, butachlor and fenoxaprop in DSR (Singh *et al*. 2012).

Physical control

Physical control is done manually or mechanically. Crops show varying sensitivity to disturbance, and monocotyledons like cereals are less sensitive than dicotyledons (Rasmussen and Accard 1995), therefore, mechanical weeding is feasible in rice. Harrowing has been found effective in direct-seeded rice, especially when the crop plants are larger than weeds to escape damage (Rasmussen and Accard 1995). Hand weeding is very easy and environment-friendly but tedious and highly labor intensive, and; thus is not an economically viable option for the farmers. It has been estimated that 150 -200-labor-day/ha are required to keep rice crop free of weeds (Roder 2001). Moreover, morphological similarity between grassy weeds and rice seedlings makes hand weeding difficult at early stages of growth. The other problems with manual weeding include quite often weeding is delayed or even cancelled due to unavailability and/or high wages of labor and damage to the rice seedlings.

Biological control

Biological weed control by using different herbivorous bio-agents such as fish, tadpoles, shrimps ducks and pigs are used to control weeds in irrigated lowland rice in a few countries but these cannot be used in aerobic rice, where there is no standing water. Weed control by mycoherbicides are now being studied to reduce herbicide dependency. The most promising fungi for biocontrol of barnyardgrass are *Exserohilum monocerus* and *Cocholiobolus lunatas*. *Setosphaeria* sp. *C. rostrata* were also found to effectively control *Leptochloa chinensis* without causing any damage to rice plant (Thi *et al*. 1999). However, scope of using mycoherbicides is also limited in controlling weeds in direct-seeded aerobic rice because such fungal pathogen requires flooded conditions. Moreover, biological control strategy is not something on which one can solely depend to control weeds especially in DSR where weed pressure is tremendous. Biological strategy should be used in conjunction with herbicides. However this is an interesting area of research where efforts can be made to develop biological control strategy which is compatible with other methods.

Chemical control

Manual and mechanical methods used to control weeds in rice could not find much place among farmers because of the high labour cost, scaricity of labour during the critical period of weed competition, and unfavourable weather at weeding time. Under such situation, herbicides have been tremendous contributor to agriculture. In large scale rice farming, herbicide based weed management has become the smartest and most viable option due to scarcity and high wages of labor (Anwar *et al*. 2012). Despite some undesirable side-effects, no viable alternative is presently available to shift the chemical dependence for weed management in rice. Many researchers working on weed management in DSR opined that herbicide may be considered to be a viable alternative/ supplement to hand weeding (Chauhan and Johnson 2011, Anwar *et al*. 2012).

Application of penoxsulam at 20, 22.5 and 25 g/ha have better control over the density of grasses and broad-leaf weeds in DSR (Singh *et al*. 2012). Singh *et al*. (2010) found effective control over the density of *C. rotundus* with the application of azimsulfuron + MSMetsulfuron-methyl. Lowest population of *E. colona* was recorded with application of pendimethalin at 2.0 kg while of *C. axillaris* was with combined application of bentazone with pendamethalin (Singh *et al.* 2005). Therefore, it is must to use herbicide judiciously (Anwar *et al*. 2012). Other herbicides that are found effective in DSR are pyrazosulfuron and oxadiragyl as pre-emergence and azimsulfuron, penoxsulam, cyhalopfop-butyl, and ethoxysulfuron as post-emergence (Rao *et al*. 2007). It must never be overlooked that all pesticides are toxic; they must be handled safely so as to reduce or avoid excessive and costly wastes, environmental concerns, crop damage, damage to adjacent crops by spray drift, injury to the applicator, excessive contamination and residues, and injury to beneficial organisms. It is advisable to rotate the herbicide combination in each year for delaying the development of herbicide resistance in weeds.

Integrated weed management

Weed-rice ecological relationships are never static. The continuous adoption of any particular rice production practice causes a shift in dominance and distribution of rice weeds. In the formation of weed management programs, the type of rice culture, cultivars grown, tillage, crop establishment methods, planting geometry, fertilizer application and water management need to be systematically manipulated so as to create favourable conditions for crop growth, but unfavourable for weed survival. Manual and mechanical weeding in DSR should be used only in

Table 3. Recommendations of herbicides for weed management in direct dry seeded rice

Herbicide (Trade name)	Dose (g/ha)	Product (g or ml/ha)	Stages of Application	Weed control
Pre-emergence herbicide				
Pendimethalin 30 EC (Stomp, Pendistar)	1000-1500	3000-4500 light to heavy soil	0-3 DAS	Controls the annual grasses and some BLWs. Could be used for weed control in wet- seeded nursery as well.
Pretilachlor 30.7% EW (Rifit, Erage-N)	450-600	1500-2000	0-3DAS	Very effective in control of grassy weeds under puddle condition. Require wet soil moisture for few days for effective weed control
Oxadiagryl 6 EC (Raft)	90	1500	0-3 DAS	Gives excellent controls of grasses and some sedge. Control of BLWs is not satisfactory
Oxyflurofen 23.5 EC (Goal and Zargon)	150-240	650-1000	0-6 DAS	Control many annual grasses, some BLWs and sedges
Anilofos 30EC (Arozin, Aniloguard)	400	1200	3-5DAS	Control many annual grasses and some BLWs. Apply on saturated soil and do not flood next 2-3 days
Oxadiazon 25EC (Ronstar)	500-750	2000-3000	Pre-em. or early post emergence	Control broad spectrum of weeds. Do not disturb the soil surface after application
Post-emergence herbicide				
Cyhalofop-butyl 10 EC (Clincher, Wrap-up)	75-80	750-800	15-20 DAS	Excellent Control of annual grasses particularly barnyard grass and *Leptochloa*
Bispyribac-sodium 10SC (Nominee gold, Adora)	20	200	15-20 DAS	Controls annual grasses and some BLWs and sedges.
Penoxsulam 24SC (Grainite)	22.5	93.7	15-20 DAS	Controls the annual grasses and some BLWs and sedges.
Chlorimuron-ethyl + Metsulfuron-methyl 20 WP (Almix)	4	20	15-20 DAS	Control broad spectrum of weeds including annual BLWs and grasses.
Ethoxysulfuron 15%WDG	12.5-15	83.3-100	15-20 DAS	Give effective control of broad-leaved and sedges.
Azimsulfuron 50WG (Segment)	35	70	20 DAS	Controls annual grasses and some BLWs and sedges
2,4-D 38 EC, 34 EF, 80 WP (Weed kill Weedmar, Knockweed etc.)	750-1000	2250-3000	20-25 DAS	Apply 20-25 days where Sedges and BLWs weeds are dominant. Drain before application of herbicide reflood again for few days. Good against water hyacinth and *Monochoria*.
Pyrazosulfuron-ethyl 10WP (Saathi)	25	200	20-25 DAS	Give effective control of broad-leaved and sedges.
Fenoxaprop-p-ethyl 6.7EC (Rice Star)	56.6-60.38	812.5-875	25-30 DAS	Excellent Control of annual grasses. May be applied as a follow up application with all pre-em. herbicide
Fenoxaprop-p-ethyl 9.3EC (Whip supar)	60-70	800-1000	25-30 DAS	

Table 4. Effect of herbicide combinations on weeds and yield of dry-seeded irrigated rice

Treatment	Dose (g/ha)	Weed density (no. /m^2) at 60 DAS			Grain yield (t/ha)
		Echinochloa spp.	*C. axillaris*	Annual sedges	
Pendimethalin	1000	1.4	108.0	181.4	3.64
Pendimethalin followed by 2,4-D	1000 *fb* 500	0.0	0.0	0.0	5.91
Pendimethalin followed by almix	1000 *fb* 4	4.0	0.0	0.0	6.06
Weedy	-	94.5	2.7	170.7	1.01
Weed free	-	-	-	-	6.32
LSD (P=0.05)	-	-	-	-	0.51

conjunction with other cultural and chemical methods to minimize labour requirements where appropriate.

None of the control measures in single can provide acceptable levels of weed control, and therefore, if various components are integrated in a logical sequence, considerable advances in weed management can be accomplished. Various agronomic tools have been evaluated for their potentiality in managing weeds (Liebman *et al.* 2001). But, all the agronomic tools may not work perfectly with every crop or weed species (Blackshaw *et al.* 2005). Integration of higher seed rate and spring-applied fertilizer in conjunction with limited herbicide use managed weeds efficiently and maintained high yields (Blackshaw *et al.* 2005). Adoption of IWM approach for sustainable rice production has been advocated by many researchers (Azmi and Baki 2002, Sunil *et al.* 2010, Jayadeva *et al.* 2011). Singh (2008) recorded that the sequential application of pre-emergence herbicides such as pendimethalin, in dry-seeded rice or early post-emergence application of anilofos/thiobencarb for the control of annual grasses in wet-seeded rice and post-emergence application of 2,4-D against sedges and non-grassy weeds in wet and dry-seeded rice may be a better option than the use of one herbicide. Some of the combinations or their sequential application may widen the weed control spectrum with better efficacy. Follow up application of 2,4-D and Almix (a ready mixture of chlorimuron-methyl and metsulfuron-methyl) as post-emergence over preemergence application of pendimethalin in DSR provided effective control of annual grasses, broad-leaf weeds and annual sedges (Table 4)

Conclusion

DSR with suitable conservation practices has potential to produce slightly lower or comparable yields as that of TPR and appears to be a viable alternative to overcome the problem of labour and water shortage. Weeds, however, are the major constraints to direct-seeded rice production. To achieve effective, long term and sustainable weed control in direct-seeded system, there is a need to integrate different weed management strategies, such as the use of a stale seeded practice, the rotation of different direct-seeded systems, the use of crop residue as mulches, the use of weed competitive cultivars with high yield potential, appropriate flooding depth and duration, appropriate agronomic practices (row spacing, seeding rates and manual or mechanical weeding), and appropriate herbicide mixtures, timing, and rotation.

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Herbicides combinations for control of complex weed flora in transplanted rice

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ABSTRACT

The puddled transplanted rice is infested with mix of grasses, sedges and broad-leaf weeds in Northern India. For control of mixed weed flora, different herbicide combinations were evaluated in a field experiment conducted in summer of 2012 and 2013 at Ludhiana. The experimental field was infested with *Echinochloa* spp., *Ischaemum rugosum, Caesulia axillaris, Cyperus iria* and *Ammania baccifera*. The performance of pre- or early post-emergence herbicides applied alone was poorer during 2012 (dry year). The differential rainfall during both the years influenced the efficacy of herbicides. The herbicide treatments integrated with hand weeding recorded good weed control during both the years. Pre-emergence application of pyrazosulfuron-ethyl at 20 g/ha + one hand weeding or bispyribac-sodium 25 g/ha applied as alone or as tank-mix with ethoxysulfuron 18.7 g/ha recorded the highest weed control efficacy, rice grain yield and net returns during both the years and seemed to be the best ways of controlling complex weed flora and enhancing productivity and profitability from transplanted rice.

Key words: Herbicides, Rainfall, Tank-mixture, Transplanted rice, Weeds

Rice (*Oryza sativa* L.) is the second major crop of Punjab, after wheat. It is traditionally raised by transplanting seedings in a puddled field. It was cultivated on 2.9 million hectares area with total production of 16.7 million tonnes during 2014-15 (Anonymous 2016). The water resources of the state, however, could support 1.6 million hectare area only. The deficit had to be met by extracting the water from ground water resources putting these resources under stress. This over-exploitation of ground water has resulted in decline in water table at the rate of 0. 74 cm/year (Vashisht 2008). This situation becomes worse in years of deficit and/or erratic monsoon. In the absence of adequate water supply, the weeds emerge at higher densities (35% more weed density and biomass) in the transplanted rice (Misra *et al.* 1981) and reduce the yield of transplanted rice by 15-20% (Reddy and Reddy 1999). Moreover, depth of the standing water influences the type and density of the weed flora (Kent and Johnson 2001, Kumar and Ladha 2011) and also efficacy of applied pre-emergence herbicides. The weed flora of transplanted rice consist of annual grasses, sedges and broad-leaf weeds. Pre-emergence herbicides like butachlor, pretilachlor, oxadiargyl, pyrazosulfuron, pendimethalin and anilofos require stagnation of water in fields for achieving effective weed control, which is not possible in all the areas owing to scarcity of irrigation water. Post-emergence application of bispyribac-sodium have been found to be effective against annual grasses and sedges; and metsulfuron-methyl, ethoxysulfuron-ethyl, bensulfuron-methyl, azimsulfuron against broad-leaf and sedges in transplanted rice. The continuous use of same herbicides having similar modes of action resulted in shift in weed problem (Rajkhowa *et al.* 2006) and development of herbicide resistance in weeds (Rao 1999). In a long term study at Ludhiana, continuous use of pretilachlor resulted in weed flora shift from *Echinochloa* spp. to *Ischaemum rugosum*, and of anilofos to *Caesulia axillaris* and *Cyperus iria* (Anonymous 2014). The use of tank-mix/ready-mix herbicide having dissimilar modes of action can be of an option for management of complex weed flora in transplanted rice (Yadav *et al.* 2008), which will not only reduce the total volume of herbicide use but also ease and economize its application. The present study was conducted to evaluate the efficiency of combination of herbicides against complex weed flora in transplanted rice.

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MATERIALS AND METHODS

A field experiment was conducted at Punjab Agricultural University, Ludhiana, Punjab during summer season of 2012 and 2013. The experimental site is situated in Trans-Gangetic Agro-Climatic zone, representing the Indo-Gangetic Alluvial plains at 30°

56' N latitude, 75°52' E longitude and at an altitude of 247 m above mean sea level. The experimental soil was loamy sand with pH 7.43 and EC 0.22 dS/m and it was low in organic carbon (0.27%) and available N (170 kg/ha) and medium in available P (20.5 kg/ha) and available K (185 kg/ha). The experiment was laid out in randomized complete block design with 3 replications. The twelve weed control treatments comprised of bispyribac-sodium (10%) 25 g/ha, pretilachlor (50%) 1000 g/ha, penoxsulam (24%) 22.5 g/ha, pyrazosulfuron-ethyl (10%) 20 g/ha, tank-mix of bispyribac-sodium 25 g + ethoxysulfuron-ethyl (15%) 18.75 g/ha, bispyribac-sodium 20 g + metsulfuron-methyl (10%) + chlorimuron-ethyl (10%) 4 g/ha, pretilachlor 750 g followed by (*fb*) ethoxysulfuron-ethyl 18.75 g/ha, pretilachlor 750 g *fb* metsulfruon + chlorimuron 4 g/ha, pyrazosulfuron-ethyl 20 g/ha *fb* manual weeding, pretilachlor (6%) + bensulfuron (0.6%) 660 g/ha, hand weeding at 25 and 45 DAT and weedy check. One manual weeding was done at 25 days after transplanting (DAT). The 30 days old seedlings of rice cv. PR 114 (2012) and PAU 121 (2013) were transplanted in puddled field during third week of June. The pre-emergence herbicides-pretilachlor, pyrazosulfruon-ethyl and pretilachlor (6%) + bensulfuron (0.6%) were broadcasted uniformly in standing water by mixing with 150 kg sand/ha at 0-5 DAT. Early-post-emergence herbicide-penoxsulam was applied by spray using 375 litres of water at 10-12 DAT. Post-emergence herbicides-bispyribac-sodium, ethoxysulfuron-ethyl, and metsulfuron-methyl (10%) + chlorimuron-ethyl were applied with hand operated knap sack sprayer fitted with flat fan nozzle by mixing with 375 litres of water/ha at 25 DAT. The field was drained before spray of early post- and post-emergence herbicides and irrigation was given one day after spray. The crop was raised as per recommended package of practices except for weed control treatments. The data on weed population and dry matter, crop growth and yield was recorded. The crop was manually harvested during third week of October. Weed data was square-root transformed before statistical analysis. The data were analyzed by using standard statistical procedures and comparisons were made at 5% level of significance.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with grasses namely *Echinochloa* spp., *Ischaemum rugosum;* sedges mainly *Cyperus iria;* and broad-leaf weeds namely *Caesulia axillaris* and *Ammania baccifera* (Table 1). The application of bispyribac-sodium either alone or tank-mixed with chlorimuron + metsulfuron or ethoxysulfuron at 25 DAT recorded effective control of mixed weed flora (Table 1 and 2) and it was at par with two hand weeded plots and pyrazosulfuron broadcasted at 0-3 DAT *fb* one hand weeding at 25 DAT. In 2012, the performance of pre- or early post-emergence herbicides applied alone was poor (with WCE varied form 1.3- 40.5%) while in 2013, all the herbicides recorded good control of weeds. In 2013, tank mix application of bispyribac with ethoxysulfuron and chlorimuron + metsulfuron

Table 1. Effect of weed control treatments on population of different weed species at 60 DAT in transplanted rice during 2012 and 2013

Treatment	Dose (g/ha)	*Echinochloa* spp.		*Ischaemum rugosum*		*Caesulia axillaris*		*Ammania*	*Cyperus iria*
		2012	2013	2012	2013	2012	2013	2013	2013
Bispyribac-Na	25	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	2.4 (9)	2.0 (5)	3.0 (17)	1.0 (0)
Pretilachlor	1000	3.0 (10)	1.7 (3)	4.4 (19)	2.1 (4)	5.6 (31)	2.0 (5)	1.0 (0)	3.1 (12)
Penoxsulam	22.5	3.1 (9)	2.4 (6)	4.8 (23)	2.3 (5)	3.8 (14)	5.8 (35)	1.7 (2)	2.4 (9)
Pyrazosulfuron	20	5.6 (30)	4.3 (19)	4.3 (18)	1.2 (1)	3.6 (15)	1.4 (1)	1.5 (2)	2.0 (5)
Bispyribac + ethoxysulfuron	25 + 18.75	3.3 (11)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Bispyribac + (chlorimuron 10% + metsulfuron 10%)	20 + 4	1.7 (3)	1.0 (0)	1.9 (4)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Pretilachlor *fb* ethoxysulfuron	750 *fb* 18.75	2.4 (6)	3.0 (10)	3.9 (15)	1.7 (3)	1.0 (0)	1.0 (0)	1.0 (0)	2.2 (7)
Pretilachlor *fb* (chlorimuron 10% + metsulfuron 10%)	750 *fb* 4	3.1 (10)	3.7 (13)	4.3 (19)	3.1 (9)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Pyrazusulfuron *fb* manual weeding	20 *fb* HW	1.5 (10)	3.1 (10)	3.1 (11)	2.1 (4)	1.0 (0)	1.0 (0)	1.0 (0)	4.0 (15)
Pretilachlor (6%) + bensulfuron (0.6%)	660	3.2 (9)	3.9 (15)	3.5 (13)	2.7 (7)	3.1 (11)	2.1 (4)	1.0 (0)	1.9 (4)
HW at 25 and 45 DAS	-	2.2 (5)	1.4 (1)	2.9 (9)	1.0 (0)	1.0 (0)	2.8 (9)	1.8 (3)	2.2 (7)
Weedy check	-	4.7 (22)	5.6 (31)	4.6 (20)	3 (9)	3.5 (15)	4.5 (20)	3.1 (9)	4.7 (23)
LSD (P=0.05)	-	1.9	1.6	1.8	1.2	2.3	2.0	NS	NS

Data is subjected to square root transformation. Figure in parentheses are original value

Table 2. Effect of weed control treatments on weed biomass at 60 DAT in transplanted rice during 2012 and 2013

Treatment	Dose (g/ha)	Weed biomass (g/m^2) Grasses		Broad-leaves		Sedges	Weed control efficiency (%)	
		2012	2013	2012	2013	2013	2012	2013
Bispyribac-Na	25	1.0 (0)	1.0 (0)	4.9 (54)	1.0 (0)	3.4 (22)	93.2	96.3
Pretilachlor	1000	17.1 (300)	4.4 (25)	12.9 (172)	2.4 (9)	3.6 (15)	40.5	91.7
Penoxsulam	22.5	20.7 (444)	6.3 (41)	7.9 (62)	3.9 (20)	5.1 (36)	36.4	83.5
Pyrazosulfuron	20	26.4 (708)	11.1 (137)	7.2 (78)	2.2 (7)	1.9 (4)	1.3	74.8
Bispyribac + ethoxysulfuron	25 + 18.75	8.0 (64)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	92.0	100
Bispyribac + (chlorimuron 10% + metsulfuron 10%)	20 + 4	6.9 (66)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	91.7	100
Pretilachlor *fb* ethoxysulfuron	750 *fb* 18.75	12.0 (152)	8.3 (94)	1.0 (0)	2.3 (8)	2.8 (13)	80.9	80.4
Pretilachlor *fb* (chlorimuron 10% + metsulfuron 10%)	750 *fb* 4	16.5 (274)	9.8 (98)	1.0 (0)	1.0 (0)	1.0 (0)	65.6	83.3
Pyrazusulfuron *fb* manual weeding	20 *fb* HW	7.5 (76)	8.6 (75)	1.0 (0)	1.0 (0)	4.5 (21)	90.5	83.6
Pretilachlor (6%) + bensulfuron (0.6%)	660	14.4 (226)	11.5 (137)	7.6 (92)	1.9 (4)	1.8 (3)	60.1	75.5
HW at 25 and 45 DAS	-	6.8 (64)	2.3 (8)	1.0 (0)	2.8 (8)	1.9 (4)	92.0	96.6
Weedy check	-	26.4 (702)	23.1 (534)	8.2 (94)	3.9 (14)	5.8 (39)	-	-
LSD (P=0.05)	-	6.4	4.8	6.6	NS	NS	-	-

Data is subjected to square root transformation. Figure in parentheses are original value

provided complete control of complex weed flora including grasses, broad-leaves and sedges (Table 1); bispyribac alone and integrated use of pyrazosulfuron with one hand weeding were at par with these two treatments ultimately resulting into the highest weed control efficiency. The benefit of tank mix of these herbicides was not recorded in 2012. The poor efficacy of pre-emergence herbicides in 2012 might be related to dry weather as only 3.5 mm rainfall was received in June. The year 2013 turned out to be wet year as 296.4 mm rainfall was received in June 2013. However, the herbicide treatments integrated with hand weeding or hand weeding alone treatment recorded similar weed control during both the years. This differential effect of rainfall on herbicides and hand weeding treatments indicated the importance of good rainfall or good soil moisture for getting best weed control from the herbicides (Phogat *et al.* 1998, Kabir *et al* 2008) and increasing water depths also increased the herbicide's efficacy. The effective control of mixed weed flora with penoxsulam 25 g/ha applied at 0-5 DAT (Pal and Banerjee 2007, Prakash *et al*. 2013), of bispyribac-sodium at 20-30 g/ha as post-emergence against *Echinochloa colona* and *Cyperus* sp. (Yadav *et al.* 2009, Kumar *et al.* 2013) and of pyrazosulfuron-ethyl at 20 and 25 g/ha applied at 3 DAT against *C. iria* (Pal *et al.* 2012) has been reported earlier.

Effect on crop and economic returns

The phytotoxicity of different herbicides on crop was observed and found variable results in two years. Tank mix application of bispyribac-sodium with chlorimuron+metsulfuron recorded 92% weed control efficiency during 2012 (dry year) but it resulted in yellowing of foliage and suppression of plant growth, and resulting in lowered rice grain yield; whereas all the herbicides were found safe to the rice crop during 2013 (wet year). The environmental factors like solar radiation, temperature, relative humidity play a significant role on bio-efficacy and phyto-toxicity of herbicides. The effective weed control in different herbicidal and integrated weed control treatments increased the number of effective tillers and the plants produced longer panicles as compared to weedy check (Table 3). The sequential application of pyrazosulfuron and one hand weeding at 25 DAT recorded the highest rice grain yield, net returns and B:C ratio in 2012 (Table 3). Pyrazosulfuron and pretilachlor alone or when followed by chlorimuron+ metsulfuron or pre-mix of pretilachlor with bensulfuron recorded rice grain yield at par to weedy check which was attributed to higher weed pressure under these treatments. Another probable reason for lower rice grain yield in 2012 might be the incidence of sheath blight in rice crop in all the plots. In 2013, bispyribac alone and as tank mix with chlorimuron + metsulfruon or with ethoxysulfuron recorded the highest rice grain yield, net returns and B:C ratio (Table 3). Pre-emergence herbicides when applied in combination with either post-emergence herbicide or manual weeding recorded more weed control efficiency, net returns and B:C ratio as compared to their sole application. Hossain and Mondal (2014) also reported higher rice grain yield with post-emergence application of bispyribac + ethoxysulfuron, pretilachlor *fb* metsulfuron-methyl + chlorimuron-ethyl, pyrazosulfuron *fb*

Table 3. Effect of weed control treatments on grain yield and yield attributes of transplanted rice during 2012 and 2013

Treatment	Dose (g/ha)	Plant height at harvest (cm)		Effective tillers (no./m^2)		Panicle length (cm)		Grain yield (t/ha)		Benefit-Cost ratio	
		2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Bispyribac-Na	25	59.7	67.6	328	363.3	22.5	25.7	4.67	7.14	1.83	2.55
Pretilachlor	1000	66.3	69.5	200	358.3	21.2	25.9	2.78	6.05	1.12	2.22
Penoxsulam	22.5	51.7	69.3	175	351.6	20.5	25.1	3.00	5.35	1.21	1.96
Pyrazosulfuron	20	54.3	63.5	113	203.3	21.4	23.3	2.72	3.29	1.10	1.21
Bispyribac + ethoxysulfuron	25 + 18.75	65.0	69.7	327	356.7	25.2	26.2	4.74	6.53	1.82	2.29
Bispyribac + (chlorimuron 10% + metsulfuron 10%)	20+4	61.1	70.9	328	368.3	23.7	26.6	3.22	7.33	1.20	2.48
Pretilachlor *fb* ethoxysulfuron	750 *fb* 18.75	55.8	69.0	241	341.7	20.5	25.3	4.44	5.87	1.79	2.15
Pretilachlor *fb* + (chlorimuron 10% + metsulfuron 10%)	750 *fb* 4	58.7	69.1	251	353.3	22.1	26.9	2.69	5.97	1.03	2.08
Pyrazusulfuron *fb* manual weeding	20 *fb* HW	59.5	68.8	331	338.3	24.4	26.6	5.89	6.68	2.13	2.20
Pretilachlor (6%) + bensulfuron (0.6%)	660	58.4	67.3	243	295.0	23.1	24.4	2.94	4.76	1.16	1.71
HW at 25 and 45 DAS	-	62.2	70.7	341	365.0	23.6	26.4	5.49	5.90	1.82	1.78
Weedy check	-	53.5	62.6	122	201.6	19.7	22.5	2.44	3.21	1.01	1.21
LSD (P=0.05)	-	NS	5.1	103.5	67.4	3.3	2.3	1.93	1.77	-	-

manual weeding, pretilachlor + bensulfuron and weed-free check than sole application of bispyribac-sodium, pretilachlor and pyrazosulfuron and early post-emergence application of penoxsulam.

The study concluded that post-emergence application of bispyribac alone and as tank-mix with ethoxysulfuron or chlorimuron + metsulfruon or pre-emergence pyrazosulfuron + one hand weeding seems to be the best ways of controlling complex weed flora and enhancing productivity and profitability from transplanted rice.

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Azimsulfuron as an effective herbicides against sedges in transplanted rice

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ABSTRACT

A field experiment was carried out at Pantnagar during *Kharif* seasons of 2013 and 2014 to know the bio-efficacy of different doses of azimsulfuron 50 DF against sedges in transplanted rice. The soil of the experimental field was clay loam in texture, medium in organic carbon (0.67%), available phosphorus (29.6 kg/ha) and potassium (176.4 kg/ha) with pH 7.2. Major sedges were: *Scirpus roylei*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea.* Application of azimsulfuron 17.5, 26.25 and 35 g/ha with 0.2% surfactant and 35 g/ha without surfactant provided complete control of *Scirpus roylei*, *Cyperus iria* and *Cyperus difformis*. The lowest dry matter of weeds was recorded with azimsulfuron with 0.2% surfactant from 17.5 to 35 g/ha, which was found at par with azimsulfuron 35 g/ha without surfactant. Among herbicidal treatments, the highest grain yield (6.12 and 6.09 t/ha) was obtained in azimsulfuron + 0.2% surfactant at 26.25 and 35 g/ha, which was significantly similar to azimsulfuron + 0.2% surfactant 17.5 g/ha and azimsulfuron 35 g/ha without surfactant.

Key words: Azimsulfuron, Sedges, Surfactant, Transplanted rice, Weed management

Rice is grown in about 45 million hectares with production of 96 million tonnes contributing 45% to the total food grain production of India. In transplanted rice, weed competition is one of the prime yield limiting biotic constraints resulting into yield reduction of 28-45% (Raju and Reddy 1995, Singh *et al*. 2003). But weeds were still the major threats, which are competing with rice for resources and thus reducing the yield levels. Pre-emergence herbicides are most commonly used against grassy weeds in transplanted rice. But post-emergence herbicides are becoming need of the day due to emergence of sedges and broad-leaf weeds at later growth stages of crop. Azimsulfuron is known to be used as post-emergence sulfonylurea herbicide for controlling weeds in rice fields (Valle *et al*. 2006). This study was undertaken to know the bio-efficacy of azimsulfuron 50 DF for the control of sedges in transplanted rice.

MATERIALS AND METHODS

A field trial was conducted during *Kharif* seasons of 2013 and 2014 at G.B. Pant University of Agriculture & Technology, Pantnagar to evaluate the bio-efficacy of azimsulfuron 50 DF. Experiment consisted of nine treatments with three doses of azimsulfuron 7.5, 26.25 and 35 g/ha with or without surfactant including bispyribac-sodium 25 g /ha as standard check as well as weed free and untreated checks. The rice variety '*HKR-47*' was used during 2013 and 2014, respectively with a spacing of 20 x10 cm. The herbicidal treatments were applied as post-emergence at 24 days after transplanting (2-4 leaf stage of weeds) of the rice crop. Herbicides were applied by using a knap-sack sprayer fitted with flat-fan nozzle using spray of 300 litres/ha. Recommended package of practices were followed to raise the crop. For measuring phytotoxicity effect, visual rating at the scale of 0-10 for azimsulfuron applied 35 and 70 g/ha with or without 0.2% surfactant was made on rice crop.

RESULTS AND DISCUSSION

The experiment field was infested mainly with *Scirpus roylei*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea* as sedges in the rice crop during 2013 and 2014 respectively. Results revealed that all the treatments gave significant control of weed population (Table 1). Application of azimsulfuron with surfactant 35 g/ha recoded significantly lowest density of sedges, *viz. Scirpus roylei*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea* and this treatment was at par to its lower doses 17.5 and 26.25 g/ha and 35 g/ha without surfactant at both the stages 30 and 45 DAS during both the years. While the application of bispyribac-sodium 25 g/ha was found least effective against the sedges. Untreated check recorded significantly higher density of sedges. Application of azimsulfuron at all the doses resulted in significant

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reduction in the dry weight of *Scirpus roylei*, *Cyperus iria*, *Cyperus difformis* and *Fimbristylis miliacea* than bispyribac-sodium and untreated check at 45 DAA during both the years. Among the herbicidal treatments, application of azimsulfuron with 0.2% surfactant from 17.5 to 35 g/ha resulted in the lowest dry weight of theses weeds which was found at par with azimsulfuron 35 g/ha without surfactant. The highest weed dry weight was registered in unweeded control plot. The results are in conformity with the findings of Saini (2003). Among the weed control treatments, application of azimsulfuron with surfactant 35 g/ha recorded 100% weed control efficiency during 2013 and 2014, respectively (Table 3), which was followed by the same herbicide with lower doses of 17.5 and 26.25 and 35 g/ha without surfactant during 2013and 2014, respectively. The weed control efficiency under bispyribac-sodium 25 g/ha was lesser than that of all the doses of azimsulfuron during both the years.

Numbers of grains per panicles, grain weight per panicles and 1000 grain weight were not influenced by different herbicidal treatments during 2013-14 and 2014-15 (Table 4). Uncontrolled weeds reduced the grain yield of rice by 60.8 and 65.9% during 2013 and 2014, respectively. All the herbicidal treatments gave significantly higher yield than weedy check during both the years. Among herbicidal treatments, the highest grain yield (6.11 and 6.09 t/ha)

Table 1. Effect of azimsulfuron 50 DF + 0.2% surf on density of weeds at 30 days after sowing in transplanted rice during 2013 and 2014

Treatment	Dose g/ha	*Scirpus roylei*		*Cyperus iria*		*Cyperus difformis*		*Fimbristylis miliacea*	Total	
		2013	2014	2013	2014	2013	2014	2013	2013	2014
Azimsulfuron 50 + 0.2% surfactant	17.5	2.7(6.7)	2.3(5.3)	1.0(0.0)	1.0(1.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	2.7(6.7)	2.3(5.3)
Azimsulfuron 50 + 0.2% surfactant	26.25	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0 (0.0)	1.0(0.0)
Azimsulfuron 50 + 0.2% surfactant	35	1.0(0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0 (0.0)	1.0(0.0)
Azimsulfuron 50	17.5	5.3(28.0)	5.0(24.0)	2.7(6.7)	2.5(5.3)	2.7(6.7)	2.5(5.3)	3.2(9.3)	6.7(48.0)	5.9(34.7)
Azimsulfuron 50	26.25	4.6(20.0)	4.2(17.7)	2.4(5.3)	1.8(2.7)	1.8(2.7)	2.0(4.0)	2.4(5.3)	5.9(33.3)	5.0(23.7)
Azimsulfuron 50	35	1.0(0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.8(2.7)	1.0 (0.0)	1.0(0.0)	1.8(2.7)
Bispyribac-sodium	25	9.0(81.3)	8.9(79.3)	3.6(12.0)	3.37(10.7)	3.9(14.7)	3.5(11.7)	4.2(17.3)	11.2(125)	10.1(101)
Weed free	-	1.0(0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0 (0.0)	1.0(0.0)
Untreated check		21.5(446)	25.4(650)	4.9(24.0)	4.8(22.7)	4.5(20.0)	4.0(15.3)	5.3(28.0)	22.8(518)	26.2(688)
LSD (P=0.05)		0.55	0.51	0.31	0.25	0.20	0.30	0.21	0.57	0.45

Values within parentheses are original. Data are subjected to square root transformation $\sqrt{x+1}$

Table 2. Effect of azimsulfuron 50DF + 0.2% surf on density of weeds at 45 days after sowing in transplanted rice during 2013 and 2014

Treatment	Dose g/ha	*Scirpus roylei*		*Cyperus iria*		*Cyperus difformis*		*Fimbristylis miliacea*	Total	
		2013	2014	2013	2014	2013	2014	2013	2013	2014
Azimsulfuron 50 + 0.2% surfactant	17.5	2.3(5.3)	2.3(5.3)	1.0 (0.0)	1.0(1.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	2.3(5.3)	2.6 (6.7)
Azimsulfuron 50 + 0.2% surfactant	26.25	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Azimsulfuron 50 + 0.2% surfactant	35	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Azimsulfuron 50	17.5	4.9(24.0)	5.0(24.0)	2.4(5.3)	2.5(5.3)	3.2(9.3)	2.5(5.3)	2.7(6.7)	6.7(45.3)	5.2 (26.6)
Azimsulfuron 50	26.25	4.1(16.0)	4.2(17.7)	2.2(4.0)	1.8(2.7)	2.2(4.0)	2.0(4.0)	2.4(5.3)	5.5(29.3)	4.2(17.4)
Azimsulfuron 50	35	1.0 (0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0 (0.0)	1.8(2.7)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)
Bispyribac-sodium	25	11.6(136)	8.9(79.3)	3.6(12.0)	3.37(10.7)	3.7(13.3)	3.5(11.7)	4.2(17.3)	13.3(178)	12.5(156)
Weed free	-	1.0(0.0)	1.0(0.0)	1.0 (0.0	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0 (0.0)	1.0(0.0)	1.0(0.0)
Untreated check		20.5(42.0)	25.4(650)	4.5(20.0)	4.8(22.7)	4.8(22.7)	4.0(15.3)	5.3(28.8)	22.1(490)	24.0(578)
LSD (P=0.05)		0.44	0.51	0.13	0.25	0.27	0.30	0.21	0.44	0.52

Values within parentheses are original. Data are subjected to square root transformation $\sqrt{x+1}$

Table 3. Effect of azimsulfuron 50DF + 0.2% surf on dry weight of weeds at 45 days after sowing in transplanted rice during 2013 and 2014

Treatment	Dose g/ha	*S. roylei*		*C. iria*		*C. difformis*		*F. miliacea*	Total		WCE (%)	
		2013	2014	2013	2014	2013	2014	2013	2013	2014	2013	2014
Azimsulfuron + 0.2% surfactant	17.5	1.3(1.8)	1.2(1.5)	1.2(1.5)	1.1(1.3)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.8(3.3)	1.7(2.8)	99.4	97.63
Azimsulfuron + 0.2% surfactant	26.25	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	100.0	100.0
Azimsulfuron + 0.2% surfactant	35	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	100.0	100.0
Azimsulfuron	17.5	4.3(18.1)	2.2(4.7)	2.0(3.0)	1.7(2.8)	3.5(12.1)	1.3(1.86)	3.4(11.1)	6.7(44.6)	3.1(9.4)	92.3	92.05
Azimsulfuron	26.25	3.1(9.3)	2.0(3.9)	1.6(1.8)	1.4(1.9)	2.9(8.1)	1.2(1.5)	2.8(7.0)	5.2(26.2)	2.7(7.3)	95.4	93.82
Azimsulfuron	35	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	100.0	100.0
Bispyribac-sodium	25	10.3(106)	5.0(24.8)	3.3(10.0)	2.1(4.4)	5.3(28.1)	2.9(8.7)	4.7(22.1)	12.9(166)	6.1(37.9)	71.1	68.1
Weed free	-	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	100.0	100.0
Untreated check		22.1(490)	10.1(103.5)	5.0(24.5)	2.6(6.5)	5.8(33.1)	2.9(8.3)	5.6(31.0)	24.0(579)	10.9(118)	0.0	0.0
LSD (P=0.05)		0.33	0.30	0.12	0.20	0.21	0.28	0.24	0.27	0.48	-	-

Table 4. Effect of azimsulfuron 50 DF + 0.2% surf on yield attributes and yield of transplanted rice during 2013 and 2014

Treatment	Dose	No. of grains / panicles		Weight of grains /panicles (g)		1000 - grain weight (g)		Grain yield (t/ha)	
		2013	2014	2013	2014	2013	2014	2013	2.014
Azimsulfuron + 0.2% surfactant	17.5	150	139	3.4	3.5	25.8	24.9	5.900	6.010
Azimsulfuron + 0.2% surfactant	26.25	153	153	3.4	3.5	25.0	24.1	6.012	6.115
Azimsulfuron + 0.2% surfactant	35	165	160	4.4	3.8	26.0	24.8	5.950	6.092
Azimsulfuron	17.5	138	142	3.3	3.5	25.5	24.9	5.622	5.708
Azimsulfuron	26.25	140	144	3.5	4.1	25.1	25.3	5.730	5.850
Azimsulfuron	35	155	137	3.9	3.5	25.9	25.8	5.900	6.070
Bispyribac-sodium	25	150	146	3.0	3.3	25.1	22.7	4.950	5.040
Weed free	-	166	164	4.4	4.1	26.1	24.4	5.990	6.095
Untreated check	-	140	147	2.9	3.6	22.0	24.8	2.333	2.074
LSD (P=0.05)		NS	NS	NS	NS	NS	NS	0.130	0.124

was found in azimsulfuron + 0.2% surfactant 26.25 and 35 g/ha, which was found significantly similar to azimsulfuron + 0.2% surfactant 17.5 g/ha and azimsulfuron 35 g/ha without surfactant. Similar observations were also made by Sharma *et al.* (2004).

There was no phytotoxicity symptoms, *viz*. yellowing, stunting and necrosis after the application of azimsulfuron 35 and 70 g/ha with and without surfactant during both the years.

On the basis of field study, it can be concluded that azimsulfuron 50 DF + 0.2% surfactant 17.5 g/ha could be the standard dose for post emergence application in rice to achieve effective control of *Scirpus roylei,Cyperus iria and Cyperus difformis.* This treatment also produced higher grain yield of rice due to effective control of these weeds.

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Sole and combined application of herbicides on composite weed flora of transplanted rice

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ABSTRACT

Field experiments were conducted during *Kharif* (wet) seasons of 2014 and 2015 at Agricultural Farm, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal, with rice variety '*MTU-7029*' to study the effect of sole and combined application of different herbicides on growth of composite weed flora and productivity of wet season transplanted rice. Eleven treatments were assigned in a randomized block design with three replications. *Echinochloa colona* and *Paspalum distichium* among the grasses; *Cyperus iria*, among the sedges and *Ludwigia parviflora* among the broad-leaved weeds were predominant throughout the cropping period. Azimsulfuron at 35 + 2, 4-D at 500 g/ha at 25 DAT effectively controlled the complex weed flora recorded at 50 DAT which was statistically at par with pretilachlor at 750 g + pyrazosulfuron-ethyl at 25 g/ha at 3 DAT. Weed competition reduced the grain yield of rice to the tune of 33-35%. Lower values of weed density, total weed dry weight and higher values of weed control efficiency and yield of rice were registered with combined application of azimsulfuron at 35 g + 2, 4-D at 500 g/ha at 25 DAT and it was followed by pretilachlor at 750 g + pyrazosulfuron-ethyl at 25 g/ha at 3 DAT. These treatments could be recommended for managing complex weed flora and obtaining higher yield of transplanted *Kharif* (wet) rice in the lateritic belt of West Bengal, India.

Key words: Azimsulfuron, Combined application, Pretilachlor, Pyrazosulfuron-ethyl, Transplanted rice, Weed management

Rice is main staple food crop of world providing food security and livelihood for millions of rural population living in tropical and sub-tropical regions of Asia. India is the second largest producer among the rice growing countries but its productivity is very low with 2.98 t/ha, while the world average is 4.25 t/ha (IRRI 2011). To sustain self-sufficiency in food and to meet future food requirements, greater emphasis should be given for increasing rice production. One of the important reasons for low riceproductivity is the infestation of weeds. Rice is generally cultivated in Eastern India by conventional transplanting. Transplanted rice is infested by heterogeneous type of weed flora which causes yield reduction by about 33-45% (Manhas *et al*. 2012 and Duary *et al*. 2015b). Manual weeding is the common practice of weed management in transplanted rice. But it is difficult, highly labour intensive and time consuming. Herbicides appear to hold a great promise in dealing with effective, timely and economic weed suppression in wet season (*Kharif)* transplanted rice. In recent past, several pre- and post-emergence herbicides have been recommended for controlling weeds in transplanted rice. However, single application of one herbicide has seldom been found effective against complex weed flora throughout the critical period of competition. Combined application of herbicides is emerging out as very effective tool to tackle the problem of complex weeds in transplanted rice. Therefore, the present experiment was undertaken to assess the effect of different herbicides either applied alone or in combination on complex weed flora and productivity of transplanted rice.

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MATERIALS AND METHODS

A field experiment was conducted on the lateritic soil of Agricultural Farm, Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal, during wet season of 2014 and 2015. The experimental field is situated at about $23^0$392 N latitude and $87^0$422 E longitude with an average altitude of 58.9 m above the mean sea level. The soil of the experimental field was sandy loam in texture with acidic in reaction (pH 6.1), low in organic C (0.39%) and available N (142.4 kg/ha), high in available P (32.13 kg/ha) and medium in available K (129.77 kg/ha). The experiment comprising of eleven treatments was laid out in randomized block design with three replications. The treatments were as follows: Pretilachlor at 750 g/ha at

3 DAT, pyrazosulfuron-ethyl at 25 g/ha at 3 DAT, azimsulfuron at 35 g/ha at 20 DAT, 2,4-D (Na-salt) at 500 g/ha at 35 DAT, ethoxysulfuron at 15 g/ha at 20 DAT, fenoxaprop-p-ethyl at 60 g/ha at 20 DAT, pretilachlor at 750 g/ha + pyrazosulfuron-ethyl at 25 g/ha at 3 DAT, azimsulfuron at 35 g/ha + 2,4-D (Na-salt) at 500 g/ha at 25 DAT, ethoxysulfuron at 15 g/ha + fenoxaprop-p-ethyl at 60 g/ha at 20 DAT, hand weeding twice at 20 and 40 DAT and unweeded control. The rice variety '*Swarna*' (*MTU-7029*) was used in the study and manual transplanting was done keeping a spacing of 20 × 10 cm. The recommended dose of fertilizers, *viz.* 80 kg N, 40 kg P_2O_5 and 40 kg K_2O /ha were applied through urea, DAP and MOP, respectively. One third quantity of nitrogen and full amount of phosphorus and potassium were applied in each plot as basal during the final land preparation. Rest two third quantity of N was applied in two splits as top dressing *i.e.* one third of nitrogen was top dressed at active tillering stage and rest one third of nitrogen was top dressed at panicle-initiation. All the herbicides alone or in combination were applied uniformly as per treatment with the help of knapsack sprayer fitted with flat fan nozzle using a spray volume of 500 L/ha. The recommended agronomic practices and plant protection measures were adopted to raise the crop. Species-wise weed density and biomass were recorded at 50 DAT by placing a quadrate of 50 x 50 cm from the marked sampling area of 1.0 m^2 in each plot. These were subjected to square root transformation to normalize their distribution. Weed control efficiency (%) was computed using the dry weight of different weed species. Weed Index (WI) was worked out using the formula as suggested by Gill and Vijayakumar (1969). Grain and straw yield of rice along with other yield-attributing characters like number of panicles/m^2, grains/panicle and test weight were also recorded at harvest.

RESULTS AND DISCUSSION

Weed flora

The experimental field comprised of weed species *Echinochloa colona, Digitaria sanguinalis, Paspalum distichium, Ludwigia parviflora, Marselia quadrifolia, Alternanthera sessilis, Eclipta alba, Commelina nudiflora, Cyperus iria* and *Fimbristylis miliacea* during both the years of study. In addition to these ten weed species, *Sphenoclea zeylanica* was observed during 2015. However, *Echinochloa colona, Digitaria sanguinalis* among the grasses; *Cyperus iria* among the sedges, and *Ludwigia parviflora* among the broad-leaved weeds were predominant throughout the cropping period (Table 1). Similar weed flora in transplanted rice has been reported by Duary (2014), Duary *et al.* (2015a and 2015b) and Teja *et al.* (2015).

Effect on weeds

The density and dry weight of different weed species were significantly reduced by herbicidal treatments and manual weeding in both the years of study. Significantly, the highest density and dry weight of all the weed species at 50 DAT were recorded in unweeded check. The lowest density as well as dry weight of the weed species was recorded with hand weeding twice at 20 and 40 DAT during both the years. Among the herbicidal treatments, application of ethoxysulfuron at 15 g + fenoxaprop-p-ethyl at 60 g/ha at 20 DAT significantly reduced the number of *Echinochloa colona* and *Paspalum distichium* at 50 DAT which was statistically at par with the combined application of azimsulfuron at 35 g + 2, 4-D at 500 g/ha and fenoxaprop-p-ethyl at 60 g/ha during both the years. Similar trend was observed in case of dry weight of *Echinochloa colona* and *Paspalum distichium* at 50 DAT (Table 1 and 2). No *Ludwigia parviflora* was registered in treatment with combined application of azimsulfuron at 35 g + 2,4-D at 500 g/ha and it was closely followed by treatments of pretilachlor at 750 g + pyrazosulfuron-ethyl at 25 g/ha and ethoxysulfuron at 15 g + fenoxaprop-p-ethyl at 60 g/ha at 25 DAT. There were significant variations among the treatments with respect to the density of *Cyperus iria*. Combined application of azimsulfuron at 35g + 2,4-D at 500 g /ha effectively controlled *Cyperus iria* and recorded the lowest number as well as dry weight at 50 DAT but it was statistically at par with treatments of pretilachlor at 750 g + pyrazosulfuron-ethyl at 25 g/ha and ethoxysulfuron at 15 g + fenoxaprop-p-ethyl at 60 g/ha at 25 DAT. Among all the herbicides, azimsulfuron at 35 g + 2, 4-D at 500 g/ha registered the lowest number of other weeds (*Digitaria sanguinalis, Marselia quadrifolia, Alternanthera sessilis, Eclipta alba, Commelina nudiflora,* and *Fimbristylis miliacea*) during both the years at 50 DAT, which was at par with pretilachlor at 750 g + pyrazosulfuron-ethyl at 25 g/ha (Table 1). Similar trend was observed in case of dry weight of other weeds species present in the experimental field recorded at 50 DAT. All the treatments were significantly superior to unweeded control in reducing the density and dry weight of total weeds. During both the years of 2014 and 2015, combined application of azimsulfuron at 35 g/ha + 2,4-D at 500 g/ha registered the lower number and dry weight of

Table 1. Effect of treatments on density of different weed species in transplanted rice at 50 DAT

Treatment	*Echinochloa colona*		*Paspalum distichum*		*Ludwigia parviflora*		*Cyperus iria*		Others		Total	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pretilachlor at 750 g/ha at 3 DAT	2.86 (7.7)	2.55 (6.0)	2.61 (6.3)	2.68 (6.7)	2.27 (4.7)	2.48 (5.7)	2.20 (4.3)	2.27 (4.7)	5.28 (27.3)	5.67 (31.7)	7.13 (50.3)	7.43 (54.7)
Pyrazosulfuron-ethyl at 25 g/ha at 3 DAT	2.74 (7.0)	2.48 (5.7)	2.80 (7.3)	2.68 (6.7)	2.04 (3.7)	2.42 (5.3)	2.04 (3.7)	1.87 (3.0)	4.14 (16.7)	5.02 (24.7)	6.23 (38.3)	6.77 (45.3)
Azimsulfuron at 35 g/ha at 20 DAT	2.12 (4.0)	1.78 (2.7)	1.87 (3.0)	1.68 (2.3)	1.68 (2.3)	1.35 (1.3)	1.87 (3.0)	1.78 (2.7)	2.86 (7.7)	2.97 (8.3)	4.53 (20.0)	4.22 (17.3)
2,4-D (Na-salt) at 500 g/ha at 35 DAT	3.34 (10.7)	2.92 (8.0)	3.44 (11.3)	3.24 (10.0)	2.20 (4.3)	1.78 (2.7)	2.48 (5.7)	2.80 (7.3)	5.08 (25.3)	5.28 (27.3)	7.60 (57.3)	7.47 (55.3)
Ethoxysulfuron at 15 g/ha at 20 DAT	3.03 (8.7)	2.61 (6.3)	2.97 (8.3)	2.68 (6.7)	2.04 (3.7)	1.87 (3.0)	1.96 (3.3)	2.04 (3.7)	3.89 (14.7)	4.45 (19.3)	6.26 (38.7)	6.28 (39.0)
Fenoxaprop-p-ethyl at 60 g/ha at 20 DAT	1.58 (2.0)	1.22 (1.0)	1.35 (1.3)	1.47 (1.7)	2.97 (8.3)	3.29 (10.3)	2.86 (7.7)	2.97 (8.3)	5.93 (34.7)	6.57 (42.7)	7.38 (54.0)	8.03 (64.0)
Pretilachlor at 750g/ha + pyrazosulfuron-ethyl at 25 g/ha at 3 DAT	1.96 (3.3)	1.78 (2.7)	1.35 (1.3)	1.58 (2.0)	1.08 (0.7)	0.91 (0.3)	1.22 (1.0)	1.35 (1.3)	1.96 (3.3)	2.27 (4.7)	3.19 (9.7)	3.39 (11.0)
Azimsulfuron at 35 g/ha + 2,4-D (Na-salt) at 500 g/ha at 25 DAT	1.68 (2.3)	1.35 (1.3)	1.22 (1.0)	1.35 (1.3)	0.71 (0)	0.71 (0)	1.08 (0.7)	1.22 (1.0)	1.47 (1.7)	1.87 (3.0)	2.48 (5.7)	2.68 (6.7)
Ethoxysulfuron at 15 g/ha + fenoxaprop-p-ethyl at 60 g/ha at 20 DAT	1.47 (1.7)	0.91 (0.3)	1.08 (0.7)	1.22 (1.0)	1.08 (0.7)	1.22 (1.0)	1.22 (1.0)	1.47 (1.7)	2.20 (4.3)	2.48 (5.7)	2.97 (8.3)	3.19 (9.7)
Hand weeding twice at 20 and 40 DAT	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
Unweeded control	3.58 (12.3)	3.19 (9.7)	3.44 (11.3)	3.39 (11.0)	3.19 (9.7)	3.14 (9.3)	2.97 (8.3)	3.29 (10.3)	6.57 (42.7)	7.25 (52.0)	9.21 (84.3)	9.64 (92.3)
LSD (P=0.05)	0.36	0.32	0.24	0.26	0.28	0.23	0.29	0.27	0.55	0.63	0.75	0.72

Figures in parentheses are the original values. The data was transformed to $\sqrt{x+0.5}$ before analysis

Table 2. Effect of treatments on dry weight of different weed species in transplanted rice at 50 DAT

Treatment	*Echinochloa colona*		*Paspalum distichum*		*Ludwigia parviflora*		*Cyperus iria*		Others		Total	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pretilachlor at 750 g/ha at 3 DAT	3.03 (8.69)	2.71 (6.85)	2.63 (6.42)	2.70 (6.77)	2.49 (5.72)	2.73 (6.96)	2.11 (3.94)	2.17 (4.19)	3.54 (12.03)	3.88 (14.58)	6.11 (36.80)	6.31 (39.35)
Pyrazosulfuron-ethyl at 25 g/ha at 3 DAT	2.80 (7.33)	2.53 (5.92)	2.56 (6.07)	2.45 (5.53)	2.04 (3.66)	2.42 (5.34)	1.81 (2.77)	1.67 (2.29)	2.54 (5.95)	3.28 (10.27)	5.13 (25.77)	5.46 (29.34)
Azimsulfuron at 35 g/ha at 20 DAT	1.98 (3.42)	1.64 (2.18)	1.67 (2.28)	1.50 (1.75)	1.70 (2.38)	1.37 (1.39)	1.66 (2.24)	1.57 (1.98)	1.77 (2.63)	2.00 (3.51)	3.67 (12.94)	3.36 (10.79)
2,4-D (Na-salt) at 500 g/ha at 35 DAT	3.48 (11.59)	3.03 (8.69)	3.55 (12.09)	3.37 (10.86)	2.32 (4.89)	1.87 (3.00)	2.38 (5.17)	2.68 (6.69)	3.54 (12.06)	3.80 (13.91)	6.80 (45.79)	6.61 (43.15)
Ethoxysulfuron at 15 g/ha at 20 DAT	2.94 (8.14)	2.51 (5.81)	2.89 (7.85)	2.61 (6.29)	2.15 (4.11)	1.95 (3.32)	1.79 (2.70)	1.86 (2.97)	2.51 (5.80)	2.93 (8.11)	5.39 (28.60)	5.20 (26.50)
Fenoxaprop-p-ethyl at 60 g/ha at 20 DAT	1.51 (1.77)	1.18 (0.89)	1.27 (1.12)	1.39 (1.43)	3.29 (10.35)	3.47(1 1.52)	2.89 (7.86)	3.01 (8.53)	3.92 (14.83)	4.34 (18.36)	6.04 (35.94)	6.42 (40.73)
Pretilachlor at 750g/ha + pyrazosulfuron-ethyl at 25 g/ha at 3 DAT	1.61 (2.09)	1.57 (1.96)	1.25 (1.07)	1.42 (1.52)	1.09 (0.69)	0.91 (0.33)	1.10 (0.72)	1.22 (0.99)	1.15 (0.82)	1.42 (1.52)	2.43 (5.38)	2.61 (6.32)
Azimsulfuron at 35 g/ha + 2,4-D (Na-salt) at 500 g/ha at 25 DAT	1.41 (1.50)	1.15 (0.82)	1.12 (0.75)	1.21 (0.97)	0.71 (0)	0.71 (0)	0.96 (0.42)	1.06 (0.61)	0.82 (0.18)	1.23 (1.02)	1.83 (2.85)	1.98 (3.42)
Ethoxysulfuron at 15 g/ha + fenoxaprop-p-ethyl at 60 g/ha at 20 DAT	1.28 (1.15)	0.89 (0.29)	1.02 (0.55)	1.16 (0.84)	1.06 (0.63)	1.19 (0.91)	1.05 (0.60)	1.21 (0.95)	1.23 (1.02)	1.46 (1.62)	2.11 (3.94)	2.26 (4.61)
Hand weeding twice at 20 and 40 DAT	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)
Unweeded control	3.78 (13.77)	3.41 (11.13)	3.57 (12.21)	3.51 (11.80)	3.58 (12.33)	3.52 (11.90)	3.03 (8.66)	3.45 (11.40)	4.75 (22.02)	5.55 (30.28)	8.34 (68.98)	8.77 (76.50)
LSD (P=0.05)	0.31	0.29	0.34	0.31	0.29	0.22	0.25	0.27	0.22	0.25	0.61	0.69

Figures in parentheses are the original values. The data was transformed to $\sqrt{x+0.5}$ before analysis total weeds which was statistically at par with pretilachlor at 750 g + pyrazosulfuron-ethyl at 25 g/ha and ethoxysulfuron at 15 g + fenoxaprop-p-ethyl at 60 g/ha at 25 DAT (Table 1 and 2). Weed control efficiency (WCE) with respect to different weed species was higher with hand weeding treatment during both years of study (Fig. 1 and 2). Among the herbicidal treatments combined application of azimsulfuron at 35 g + 2,4-D at 500 g/ha applied at 25 DAT resulted into higher weed control efficiency against different weed species but it was closely followed by the treatment of pretilachlor at 750 g + pyrazosulfuron-ethyl at 25 g/ha. The lower value of weed index was recorded with the combined application of azimsulfuron at 35 g + 2,4-D at 500 g/ha and pretilachlor at 750 g + pyrazosulfuron-ethyl at 25 g/ha (Fig. 3). Similar results were reported by Jayadeva *et al.* (2009), Kumar *et al.* (2014), Duary *et al.* (2015b) and Teja *et al.* (2015).

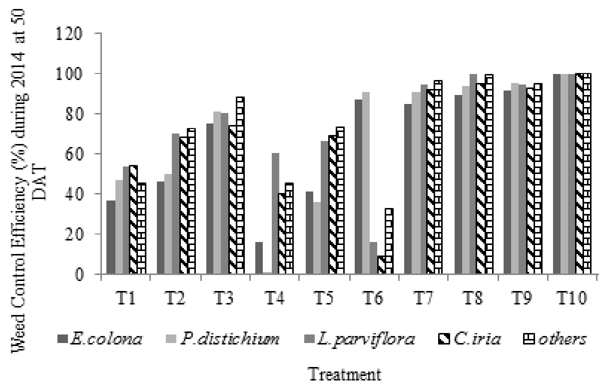

Fig. 1. Effect of treatments on weed control efficiency of different weed species in transplanted rice during 2014 at 50 DAT

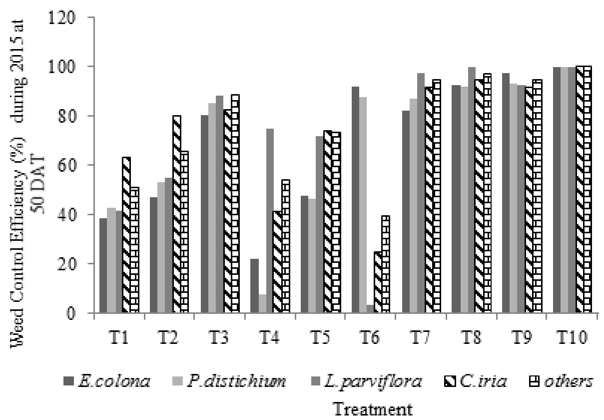

Fig. 2. Effect of treatments on weed control efficiency of different weed species in transplanted rice during 2015 at 50 DAT

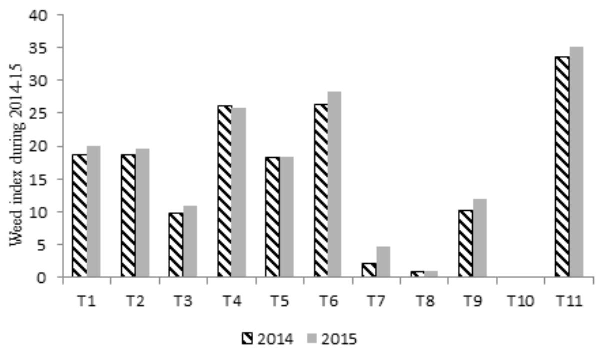

Fig. 3. Effect of treatments on weed index of transplanted rice during 2014 and 2015

Effect on crop

All the weed management treatments registered significantly higher values of yield and yield attributes like number of panicles, number of grains per panicle and test weight of transplanted rice over the unweeded control. The highest number of panicles/m^{2}and number of grains/panicle were recorded with hand weeding twice at 20 and 40 DAT during both the years. But among the other treatments, combined application of azimsulfuron at 35 g + 2, 4-D at 500 g/ha registered the highest number of panicles/m^2 and number of grains/panicle, which was statistically at par with pretilachlor at 750 g + pyrazosulfuron-ethyl at 25 g/ha during both the years of study (Table 3). Test weight did not vary significantly among the treatments. Weed competition in unweeded control plot resulted in 33-36% reduction in grain yield of transplanted *Kharif* rice. Similar yield reduction in wet season rice due to weed competition in the lateritic belt of West Bengal was also reported by Duary (2014), Duary *et al.* (2015a) and Teja *et al.* (2015). During both the years, the highest grain yield was recorded under hand weeding twice at 20 and 40 DAT treatment but it was statistically at par with azimsulfuron at 35 g + 2,4-D at 500 g/ha and pretilachlor at 750g + pyrazosulfuron-ethyl at 25 g/ha, azimsulfuron at 35 g/ha at 20 DAT (Table 3). Effective and timely weed management under these treatments reduced the density as well as dry weight of weeds consequently resulting into increased number of panicles/m^2, number of grains/panicle and finally the yield. The results were in conformity with the findings of Jayadeva *et al.* (2009), Kumar *et al.* (2014), Shyam and Singh (2015), Duary *et al.* (2015b) and Teja *et al.* (2015). Similar trend was observed in case of straw yield of transplanted rice. Unweeded control registered the lowest grain and straw yield during both years of study.

Table 3. Effect of treatments on yield attributes, yield and economics of transplanted rice

Treatment	No of panicles/m^2		No. of grains/ panicle		Test weight (g)		Grain yield (t/ha)		Straw yield (t/ha)	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pretilachlor at 750 g/ha at 3 DAT	219	214	123	128	19.8	20.5	4.24	4.33	4.97	4.98
Pyrazosulfuron-ethyl at 25 g/ha at 3 DAT	217	218	127	124	19.5	20.2	4.23	4.35	4.95	4.98
Azimsulfuron at 35 g/ha at 20 DAT	241	243	138	141	20.5	20.9	4.70	4.82	5.29	5.36
2,4-D (Na-salt) at 500 g/ha at 35 DAT	189	192	108	108	20.0	19.6	3.85	4.01	4.62	4.56
Ethoxysulfuron at 15 g/ha at 20 DAT	219	221	122	125	20.5	20.3	4.26	4.42	4.97	4.96
Fenoxaprop-p-ethyl at 60 g/ha at 20 DAT	194	187	110	107	19.8	19.5	3.83	3.88	4.60	4.58
Pretilachlor at 750 g/ha + pyrazosulfuron-ethyl at 25 g/ha at 3 DAT	261	265	149	155	20.6	21.2	5.09	5.15	5.62	5.72
Azimsulfuron at 35 g/ha + 2,4-D (Na-salt) at 500 g/ha at 25 DAT	270	276	157	164	20.8	21.4	5.16	5.36	5.67	5.76
Ethoxysulfuron at 15 g/ha + fenoxaprop-p-ethyl at 60 g/ha at 20 DAT	231	232	134	138	20.2	20.3	4.68	4.76	5.28	5.31
Hand weeding twice at 20 and 40 DAT	270	281	160	166	20.9	21.2	5.21	5.41	5.69	5.81
Unweeded control	164	156	95	89	19.3	19.4	3.46	3.51	4.25	4.18
LSD (P=0.05)	21	18	10	12	NS	NS	0.36	0.32	0.32	0.36

Based on present investigation, it was inferred that combined application of azimsulfuron at 35 g + 2, 4-D at 500 g/ha at 25 DAT or pretilachlor at 750 g + pyrazosulfuron-ethyl at 25 g/ha at 3 DAT were very effective against the composite weed flora and registered higher yield of transplanted *Kharif* (wet) rice and this outcome could be very useful for the farmers of the lateritic belt of West Bengal.

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Mechanized weed management to enhance productivity in System of Rice Intensification (SRI)

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ABSTRACT

Rice ecosystems including irrigated rice in India is infested with complex weed flora including semi-aquatic and aquatic weeds which cause yield losses from 15 to 76% in rice crop. ICAR-Indian Institute of Rice Research (IIRR) under All India Co-ordinated Rice Improvement Programme (AICRIP) has conducted experiments across India (11 locations) to evaluate System of Rice Intensification (SRI) method, assessing their potential and the effects of individual SRI practices for enhancing productivity under different agro-ecological conditions compared to standard normal transplanting (NTP) method. SRI method recorded significantly higher grain yield (6.22 t/ha) followed by integrated crop management (ICM) (6.07 t/ha), standard practice of transplanting (5.60 t/ha) and direct seeding with drum seeder (5.13 t/ha). The effect of cono-weedings on grain yield indicated the superiority of 4 times cono weeding (10, 20, 30 and 40 DAT) which recorded better yields over two times cono weeding and the reduction in yield to the tune of 5.7- 11.8% by 2 times cono weeding *i.e.* 10 and 20 DAT (5.7% less) and herbicide application (11.8% less), respectively. Based on multi-location testing, results indicated that SRI has the potential to enhance the productivity of the rice with reduced inputs in different agro-ecological situation and soil types across the country and weeding by cono weeder with reduction in drudgery of weeding in rice.

Key words- Mechanised weed management, System of Rice Intensification (SRI), Productivity of rice

Rice (*Oryza sativa* L.) is one of the most important staple food crops in the world. With an average productivity of 2.49 t/ha, though increasing marginally, but is still well below the world's average yield of 4.36 t/ha (FAOSTAT 2014). To maintain self-sufficiency, the present production level of 105 million tonnes needs to be increased up to 125 million tonnes by the year 2020 (Chandrasekaran 2008). Growing rice by System of Rice Intensification (SRI) method is a novel approach of rice cultivation, which saves water and other inputs (Satyanarayana 2007) through effective integration of crop, soil, water and nutrient management (Uphoff 2003).

Weed competition is one of the prime yield limiting biotic constraints in rice. In view of the increasing labour scarcity and negative impact of indiscriminate herbicide use, weed management strategy needs to be re-oriented towards mechanical means for satisfactory monetary benefits. Rotary weeder was effective in controlling weeds in inter row space as SRI method maintains a spacing of 25 cms at both the directions. The present study was undertaken with an objective to study the effect of different weed management options in SRI and their effect on grain yield at different locations.

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MATERIALS AND METHODS

The field experiment included four establishment methods conducted at 11 locations *viz.*, Aduthurai, ARI-Rajendranagar, Coimbatore, Jagdalpur, Nawagam, Karjat, Pusa, Chiplima, Mandya, Siruguppa and Malan during 2004 and 2005 *Kharif* with standard practice of planting (S1), system of rice intensification method -SRI (S2), integrated crop management and modified mat nursery in transplanted rice -ICM (S3) and direct seeding with drum seeder -DS (S4). The nursery area was about 100 m^2/ha. The sprouted seed were sown on raised beds of 5 beds of 20 m^2 and watered frequently to keep wet. Twelve days old seedlings were pulled very carefully by using trays and planted single seedlings at shallow depth of 1-2 cm and spacing of 25 x 25 cm (Gopalakrishnan *et al.* 2014).

Weed management in SRI consisted of three treatments, two times cono weeding (10 and 20 DAT), four times cono-weeding (10, 20, 30 and 40 DAT) and herbicide pre-emergence butachlor 1.5 kg/

ha followed by one hand weeding at 10 locations in *Kharif* (2009 and 2010) and 7 locations in *Rabi* (2009-10 & 2010-11). The data was analyzed based on Fishers method of analysis of variance technique for interpretation of the data as outlined by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Performance of system of rice intensification was better in terms of grain yield at all the locations tested in India compared to other methods of establishment. In Arundhatinagar, SRI recorded highest grain yield (8.59 t/ha) followed by Coimbatore (7.91 t/ha) and least grain yield was at Chiplima (4.34 t/ha). Overall, SRI method recorded significantly superior grain yield of 2.32%, 9.92% and 17.5% over integrated crop management (ICM), standard practice of transplanting and direct seeding with drum seeder, respectively. The lowest grain yield was observed at direct-seeding with drum seeder at most of the locations. Higher grain yield realized with SRI method may be due to the use of younger seedlings, transplanted at shallow depth with wider spacing, repeated cono weeding during vegetative growth (Kumar *et al.* 2011).

Effect of weed management practices on grain yield

Among the weed management practices followed in SRI method, four times cono weeding at 10, 20, 30 and at 40 DAT recorded superior grain yield at all the locations during both *Kharif* and *Rabi* seasons (5.90 and 5.45 t/ha) over pre-emergence butachlor 1.5 kg/ha followed by one hand weeding (5.28 and 4.93 t/ha) and 2 times cono weeding at 10 and 20 DAT (5.57 and 4.71 t/ha), respectively. Whereas in *Kharif* season, two times cono weeding at 10 and 20 DAT performed better and recorded higher grain yield than herbicide application but in *Rabi* season pre-emergence butachlor 1.5 kg/ha followed by one hand weeding showed higher grain yield than 2 times cono weeding at 10 and 20 DAT.

Overall, in *Kharif* season, the effect on grain yield due to weed management practices indicated the superiority of four times cono weeding (10, 20, 30 and 40 DAT) as compared to two times cono weeding and herbicide application which recorded 11.8% and 5.7% less grain yield, respectively. In *Rabi* season there was no significant yield difference due to weed management practices, however, 4 times cono weeding (10, 20, 30 and 40 DAT) recorded higher grain yield (5.45 t/ha) followed by herbicide application (4.93 t/ha) and lowest grain yield was observed with 2 times cono weeding (4.71 t/ha) (Mohapatra *et al.* 2012). SRI with cono weeding four times at 10 days interval resulted in significantly lower weed biomass (Uprety 2010). The use of cono weeder caused 10-17% increase in grain yield during wet season (Mandal *et al.* 2013). Cono weeder further reduced man-days required for weeding from 30 to 10 (Mrunalini and Ganesh 2008), thus helped saving labour and time. Higher numbers of cono weeding effectively buries and incorporates the weeds into soil and minimizes the weed competition. Further it improves the soil aeration, root development, nutrient absorption and more number of tillers, which favoured the crop growth, yield attributes and resulted in higher grain yield (Table 2 and 3). The same findings were confirmed with other researchers (Thiyagarajan *et al.* 2007, Kavitha *et al.* 2010).

It was concluded that SRI method is a promising technology over integrated crop management, standard practice of transplanting (5.60 t/ha) and direct-seeding with drum seeder in terms of higher grain yield across the locations. The effect of cono weeding was promising over hand weeding and herbicides and indicated the superiority of 4 times cono weeding (10, 20, 30 and 40 DAT) followed by 2 times cono weeding (5.7% less) and herbicide application (11.8% less). There is a need to economise the mechanical weeding operations and development of cost effective efficient motorized

Table 1. Effect of different establishment methods on grain yield of rice at different locations across the India (mean of two years)

Treatment	Location											
	ARI, R' Nagar	Siruguppa	Mandya	Coimbatore	Aduthurai	Jagdalpur	Karjat	Nawagam	Malan	Chiplima	Arundhatinagar	Mean
S_1	5.76	5.63	5.58	6.17	4.73	5.67	6.24	5.99	5.54	4.73	5.61	5.60
S_2	6.61	4.96	6.31	7.91	6.50	5.67	6.69	5.88	4.78	4.34	8.59	6.22
S_3	6.03	4.85	6.14	7.05	6.56	5.71	6.65	5.77	4.89	5.11	8.09	6.07
S_4	4.49	5.70	5.91	5.82	4.11	4.97	5.78	5.30	4.69	4.15	5.54	5.13
Mean	5.72	5.29	5.99	6.74	5.48	5.51	6.34	5.74	4.98	4.63	6.96	5.76
LSD (P=0.05) 0.557												

S_1- Standard practice of planting; S_2-System of rice intensification method (SRI); S_3-Integrated crop management and modified mat nursery in transplanted rice (ICM); S_4-Direct seeding with drum seeder

Table 2. Effect of weed management practices on grain yield (t/ha) of rice under system of rice intensification at different locations across India (mean of *Kharif* 2009 and 2010)

Treatment	Aduthurai	ARI-Rajendranagar	Chatha	Coimbatore	Puducherry	Pantnagar	Gangavathi	Karjat	Ranchi	Pusa	Mean
T_1	7.02	5.81	4.05	5.89	4.69	4.80	4.10	5.57	6.08	7.66	5.57
T_2	7.24	5.91	4.49	6.58	4.91	5.19	4.25	6.19	6.14	8.05	5.90
T_3	5.45	6.00	3.40	6.13	4.67	4.00	4.82	6.15	5.56	6.57	5.28
Mean	6.57	5.91	3.98	6.20	4.76	4.66	4.39	5.97	5.93	7.43	5.58
LSD (P=0.05) 0.417											

T_1: 2 times cono weeding (10 and 20 DAT); T_2: 4 times cono weeding (10, 20, 30 1nd 40 DAT); T_3: pre-emegence butachlor 1.5 kg/ha followed by one hand weeding

Table 3. Effect of weed management practices on grain yield (t/ha) of rice under system of rice intensification at different locations across India (*Rabi*, 2009 -2010)

Treatment	Aduthurai	Arundhati Nagar	Annamalai Nagar	Coimbatore	Karjat	Mandya	Puducherry	Mean
T_1	6.85	6.80	1.73	4.59	4.23	4.14	4.61	4.71
T_2	7.44	6.73	2.52	5.87	5.13	5.12	5.36	5.45
T_3	4.58	7.30	3.63	5.55	4.71	4.67	4.05	4.93
Mean	6.29	6.94	2.63	5.34	4.69	4.64	4.67	5.03
LSD(P=0.05) 0.899								

T_1: 2 times cono weeding (10 and 20 DAT); T_2: 4 times cono weeding (10, 20, 30 1nd 40 DAT); T_3: pre-emegence butachlor 1.5 kg/ha followed by one hand weeding

weeders for popularization of the SRI for its large scale adoption in India. However, the use of cono weeder may be exploited as a component of IWM in low land and irrigation rice as a strategy of integrated weed management practices available in the region.

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Grassy weed management in aerobic rice in Indo-Gangetic plains

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ABSTRACT

A replicated field experiment was conducted during 2014 and 2015 to determine the efficacy of herbicides under aerobic soil conditions for selecting suitable herbicide dose towards successful grassy weed management in rice at Krishi Vigyan Kendra Farm, Ashokenagar, West Bengal, India. The results clearly indicated the positive response of herbicide on grassy weeds. Among the herbicide treatments, metamifop 10 EC 125 g/ha resulted in lower number of weed population, (15.67 and 10.90) and higher weed control efficiency 91.55% and 92.60%), during 2014 and 2015, respectively. On an average 64.5% grain yield was recorded over the control. Application of metamifop at 2-3 leaf stage could be the possible alternative options for effective and economic weed control in rice under aerobic system to avoid development of herbicide resistance in weed.

Key words: Aerobic rice, Grasses, Herbicides, Weed control efficacy, Yield

Aerobic rice systems, wherein the crop is established through direct-seeding in non-puddled, non-flooded fields, are among the most promising approaches for saving water (Bhushan *et al.* 2007). Weeds pose a serious threat to the direct-seeded aerobic rice by competing for nutrients, light, space and moisture throughout the growing season (Hussain *et al.* 2008). In aerobic direct-seeded rice, loss of grain yield due to weed competition ranged from 38 to 92% (Singh *et al.* 2008). Therefore, developing a sustainable weed management approach has been a challenge for widespread adoption of aerobic rice technology. Hand weeding is very easy and environment-friendly but tedious and highly labour intensive (Adhikary *et al.* 2014). Farmers very often fail to remove weeds due to unavailability of labor at peak periods (Adhikary and Ghosh 2014). Moreover, morphological similarity between grassy weeds and rice seedlings makes hand weeding difficult at early stages of growth. The weed flora composition and their abundance in aerobic rice differ from that of puddled flooded rice system (Mahajan *et al.* 2009). Information regarding weed flora composition and their response to different herbicides in aerobic rice system is meager. In general, most of the soil applied rice herbicides require moist or even flooded condition for their efficient actions against weeds which is not satisfied under aerobic system. Therefore, the efficacy of herbicides under aerobic soil conditions needs to be evaluated for selecting suitable herbicides towards successful grassy weed management in this system.

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MATERIALS AND METHODS

The experiment was conducted during two consecutive *Kharif* seasons of 2014 and 2015 at the Krishi Vigyan Kendra Farm, Ashokenagar (latitude: 22° 50' 9.6324'' N, longitude: 88° 38' 13.8192'' E and altitude: 10.47m) West Bengal, India. This soil was medium in organic carbon content (0.67%) and the available nutrient status was low in nitrogen, medium range of phosphorus and the potassium status was high with neutral to alkaline in soil reaction. The variety used in this experiment was '*IET-4786*'. The experiment was laid out in randomized block design with seven treatments, *viz.* metamifop 10 EC 75 g/ha, metamifop 100 g/ha, metamifop 125 g/ha, cyhalofop-butyl 10 EC 80 g/ha, cyhalofop-butyl 100 g/ha, two hand weeding at 20 and 40 DAS and control. The test herbicides were sprayed as early post-emergence (2-3 leaf stage) with the spray volume of 500 liters/ha using knapsack sprayer with flood jet deflector WFN 040 nozzle. All the other recommended agronomic and plant protection measures were adopted to raise the crop and the intercultural practices were taken as need based. The data on weed counts and dry matter production (DMP) were recorded at 30 days after application (DAA) and weed control efficiency (WCE) of different treatments was computed using data on weed DMP. The leaf chlorophyll content was quantified by using a chlorophyll meter (Minolta SPAD 502) at 15, 30, 45, 60, 75 and 90 DAS. The data were analyzed following analysis of variance (ANOVA) technique and mean differences were adjusted by the multiple comparison test (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Effect on weeds

Metamifop 10 EC at 125 g/ha at 2 - 3 leaf stage recorded the lowest grassy weed density (15.7 and 10.9 in 2014 and 2015, respectively) (Table 1) and it was comparable with metamifop 100 g/ha and cyhalofop-butyl 80 g/ha. The above dosages reigned superior in weed control than the lower dose of metamifop 75 g/ha and higher dose of cyhalofop-butyl 00 g/ha. The hand weeding plots recorded the lowest weed density (14.3 and 10.1) during 2014, 2015, respectively. Unweeded control recorded the highest total weed density. The control of the grasses by the metamifop treatments and the cyhalofop-butyl has shown the corresponding similar trend in the total weed density (Table 1).

The twice hand weeding recorded the lowest grassy weed dry weight in both crop seasons. Among the herbicide treatments, lower grassy weed dry weight was recorded with application of metamifop 125 g/ha at 2 - 3 leaf stage followed by metamifop 100 g/ha and cyhalofop-butyl 80 g/ha, which were comparable with each other (Table 1). While the unweeded control treatment recorded higher grass weed dry weight.

During both the seasons, hand weeding plots registered highest weed control efficiency of 92.1 and 93.4% in 2014, 2015, respectively (Table 1). This finding was of agreement with Adhikary and Ghosh (2014). Among the herbicides, higher weed control efficiency was recorded with application of metamifop 125 g/ha followed by metamifop 100 g/ha and cyhalofop-butyl at 80 g/ha, which remained comparable with each other. The above three treatments gave significantly higher weed control efficiency than the lower dose of metamifop 75 g/ha and higher dose of cyhalofop-butyl 100 g/ha.

Effect on leaf chlorophyll content

Different doses of herbicide treatments had significant effect on leaf chlorophyll content in two season's trial for all these observation dates. The highest value was obtained with application of metamifop 125 g/ha followed by cyhalofop-butyl 80 g/ha and metamifop 100 g/ha in respective of observation dates. The lowest leaf chlorophyll content was recorded in control plots (Table 2). The chlorophyll content value obtained in the hand weeded plots was statistically similar to those obtained for herbicide treated plots. Higher yield in weed free plots or different herbicide treated plots may be attributed to their efficiency of weed control resulting in higher photosynthetic capacity as reflected by high SPAD value. The SPAD meter provides a very easy, swift and non destructive method for estimating relative leaf chlorophyll content. Higher SPAD values indicate greener and healthier plants. In this study, the SPAD values for the weedy plots were lower than the weed free treatments. It was further noticed that the SPAD value of the herbicide treated plots significantly varied from that of weed free plots. Moreover, in some cases the SPAD values of the herbicide treated plots were higher than that of weed free plots indicating healthier plants in the herbicide treated plots. This result suggested that the herbicide application does not create negative impact on leaf chlorophyll content and photosynthesis of rice crop (Suria *et al.* 2011). The lower SPAD value is associated with high weed interference resulting in yield decrease in aerobic rice (Anwar *et al.* 2010).

Effect on growth parameters

Results on plant height as affected by herbicide rates (Table 2). Data indicated that metamifop application irrespective of rates contributed to taller plants as compared to cyhalofop-butyl treated plots.

Table 1. Effect of herbicides on total grass count, weed dry weight and weed control efficiency in aerobic rice

Treatment	2014			2015		
	Total grass count (no./m^2)	Weed dry weight (g/m^2)	Weed control efficiency (WCE %)	Total grass count (no. /m^2)	Weed dry weight (g/m^2)	Weed control efficiency (WCE %)
Metamifop 75 g/ha	5.7 (31.2)	4.3 (17.8)	77.1	5.1 (25.0)	3.8 (13.6)	80.3
Metamifop 100 g/ha	4.4 (18.6)	2.9 (7.6)	89.1	3.9 (14.1)	2.7 (6.1)	91.1
Metamifop 125 g/ha	4.1 (15.7)	2.6 (5.8)	91.5	3.4 (10.9)	2.5 (5.1)	92.6
Cyhalofop-butyl 80 g/ha	4.5 (19.1)	3.0 (8.0)	88.4	3.9 (14.1)	2.7 (6.3)	90.8
Cyhalofop-butyl 100 g/ha	5.8 (32.4)	4.1 (15.8)	74.3	4.9 (23.6)	3.5 (11.6)	83.2
Two hand weeding at 20 and 40 DAS	3.9 (14.3)	2.5 (5.5)	92.1	3.3 (10.1)	2.4 (4.6)	93.4
Control	9.3 (85.7)	8.4 (69.1)	0	9.0 (79.6)	8.4 (69.2)	0
LSD (P=0.05)	0.64	0.51	-	0.58	0.50	-

*Data in the parentheses are original value; ** Square root transformed value of $(\sqrt{x+1})$ was used for statistical analysis

It might be due to the fact that metamifop treatment at early crop growth stages suppressed weed population effectively which resulted in higher vigour and growth of rice plants. Plant height increased in hand weeding plots even better than in metamifop treated plots.

First flowering was noticed to be induced slightly earlier in metamifop treated plots as compared to cyhalofop-butyl treated plots (Table 3). Similar trend was noticed in case of days to 50% flowering. However, the difference was not considerable with hand weeding plots as well as unweeded treatments. Maturity, however, came slightly earlier in metamifop treated plots compared to cyhalofop-butyl treated ones. However, the differences among the treatments were non-significant. These inferences are supported with the work of Bari (2010) who obtained varying level of tillers dynamics, plant height and phenology with the use of herbicides.

Yield attributes and yield

During both the seasons, significantly, highest numbers of panicles/m^2 (274.16 and 285.12 in 2014, 2015, respectively) were recorded with hand weeding plots which remained as compared with metamifop 125 g/ha (252.67 and 262.54 in 2014 2015, respectively). This was followed by metamifop 100 g/ha and cyhalofop-butyl 80 g/ha treatments (Table 4). Lower number of panicles/m^2 was observed in unweeded control. There was no significant difference in the test weight (1000 grain weight) of grains observed between the treatments during both seasons.

Data on grain yield revealed that in *Kharif* 2014, metamifop application contributed better than cyhalofop-butyl (Table 4). The highest grain yield 3.469 t/ha was harvested in the hand weeding treatment being followed by 3.425 t/ha in the treatment where metamifop was applied at 125 g/ha. Among the cyhalofop-butyl treatments, the highest grain yield of 3.409 t/ha was contributed by cyhalofop-butyl 80 g/ha. metamifop at 75 g/ha and higher dose of cyhalofop-butyl at 100 g/ha treatments contributed to higher grain yields over control plots, however, much lower than the hand weeded plots and rest three chemical treatments. Similar trend of observations were recorded in *Kharif* 2015. The increase in rice grain yield with efficient weed control treatments may be attributed to better crop growth due to reduced weed-crop competition for any of the growth factor. The present findings are corroborated with the previous work of Nithya *et al.* (2012), who observed that weed infestation of 100-200 weeds/m^2 reduced paddy yield by 51-64% compared with weed-free conditions. Rice plots without such competition recorded higher number of productive tillers over control because of the greater space capture by rice plants. The canopy closure occurred earlier due to

Table 2. Effect of herbicides on leaf chlorophyll content of aerobic rice (pooled over two seasons)

Treatment	Plant height (cm)	Leaf chlorophyll content					
		15 DAS	30 DAS	45 DAS	60 DAS	75 DAS	90 DAS
Metamifop 10 EC 75 g/ha	76.7	24.1	33.8	35.0	39.5	42.3	43.9
Metamifop 10 EC 100 g/ha	81.5	24.8	34.0	35.7	40.0	42.9	44.0
Metamifop 10 EC 125 g/ha	89.3	27.1	37.7	37.5	43.1	45.0	46.4
Cyhalofop-butyl 10 EC 80 g/ha	86.9	26.9	36.0	37.0	42.2	44.0	44.8
Cyhalofop-butyl 10 EC 100 g/ha	79.5	24.2	34.4	36.4	40.0	42.3	43.9
Two hand weeding at 20 and 40 DAS	88.8	25.0	33.2	35.1	39.9	43.1	44.3
Control	70.8	22.3	26.4	27.8	32.7	34.2	35.1
LSD (P=0.05)	2.4	1.0	1.1	1.0	1.2	1.4	1.6

Table 3. Effect of herbicides on phonological events of aerobic rice (pooled over two seasons)

Treatment	Days				
	1st flowering	50% flowering	Difference between 1st and 50% flowering	Maturity	Difference between 1st flowering and maturity
Metamifop 10 EC 75 g/ha	69.7	74.7	5.00	108	38.3
Metamifop 10 EC 100 g/ha	69.8	74.3	4.53	109	38.9
Metamifop 10 EC 125 g/ha	70.5	74.5	4.00	107	36.8
Cyhalofop-butyl 10 EC 80 g/ha	70.0	76.0	6.00	109	38.7
Cyhalofop-butyl 10 EC 100 g/ha	70.3	75.5	5.17	108	38.0
Two hand weeding at 20 and 40 DAS	70.5	75.3	4.83	110	39.8
Control	67.0	72.0	5.00	110	43.0
LSD (P=0.05)	NS	NS	NS	NS	NS

Table 4. Effect of herbicides on yield attributing parameters of aerobic rice

Treatment	2014			2015		
	No. of panicles/ m^2	Test weight (g)	Grain yield (t/ha)	No. of panicles/ m^2	Test weight (g)	Grain yield (t/ha)
Metamifop 75 g/ha	181	22.8	3.17	196	24.1	3.09
Metamifop 100 g/ha	239	23.8	3.42	240	24.6	3.37
Metamifop 125 g/ha	253	24.3	3.42	262	23.9	3.41
Cyhalofop-butyl 80 g/ha	226	23.1	3.41	232	24.1	3.33
Cyhalofop-butyl 100 g/ha	196	24.8	3.18	204	24.3	3.11
Two hand weeding at 20 and 40 DAS	274	23.3	3.47	285	24.0	3.40
Control	127	24.7	2.10	133	24.5	1.92
LSD (P=0.05)	17	NS	0.22	15	NS	0.24

better competitive ability and nutrient efficiency. Mahajan *et al.* (2009) concluded that herbicides are the most effective means of securing rice yields against weeds. Data indicated that in 1st year *i.e.* 2014, metamifop treated plots contributed to yield increase ranging from 50.71% to 62.94% with an average value of 58.89% over the control plots, while the respective increase in yield for cyhalofop-butyl was 62.17%. Whereas in 2015, the metamifop and cyhalofop-butyl treated plots contributed 70% and 67% grain yield, respectively, over control. But in both years maximum grain yield *i.e.* 65.03% (2014) and 76.66% (2015) were recorded in hand weeding treatment. The findings were not out of new in that similar findings have been reported by Nithya *et al.* (2012). Reason for the better yield advantage in all the weed control treatments implementing is traceable to reduction in weed competition. Data further revealed inclining trends in yield increase with the increase in metamifop rate, although yield was in declining trend when concentration crossed the recommended dose of cyhalofop-butyl. These findings were further supported with the work of Daniel *et al.* (2012). Nithya *et al.* (2012) found better yields in aerobic rice with the application of metamifop 125 g/ha. From data presented it might reasonably be argued that early post-emergence herbicides offered early season weed control up to the period of full canopy cover by rice plants, which might also contributed to higher grain yield. Application of metamifop at lower dosages could not bring the desired benefits as weeds grew luxuriantly and competed with the crop for resources like nutrients, solar radiation, water and space.

Application of metamifop at 125g/ha at 2-3 leaf stage could be the possible alternative options for effective and economic weed control in rice under aerobic system towards avoiding development of herbicide resistance in weed. The selected herbicide could be used in rotation for sustainable weed management and to run the aerobic rice system as a profitable business venture.

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Herbicide combinations for weed management in direct-seeded rice

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ABSTRACT

Ten treatments were evaluated during *Kharif* 2013, 2014 and 2015 at Palampur (Himachal Pradesh) to study their impacts on weeds, crop and economics. *Echinochloa colona* was the most competitive weed followed by *Aeschynomene indica* and *Panicum dichotomiflorum*. Oxadiargyl *fb* bispyribac, pyrazosulfuron *fb* bispyribac, pendimethalin *fb* bispyribac *fb* manual weeding and bispyribac + chlorimuron + metsulfuron-methyl gave significantly lower count of *E. colona* and *Panicum dichotomiflorum*. The economic threshold levels (no/m^2) with the weed management practices studied varied between 2.5-17.8/m^2. With every 1 weed/m^2 increase in density, the grain yield of dry-seeded rice was reduce by 62.4 kg/ha. Manual weeding engaged more labour and had higher cost tending to increase the economic threshold over herbicidal treatments. Cost of weed control under herbicidal/integrated treatments was 14 - 49% of weed free and 19.9 - 69.3% of that under mechanical weeding. Oxadiargyl *fb* bispyribac resulted in highest net return due to weed control. Crop resistance index and efficiency index were highest and weed index was minimum under pendimethalin *fb* bispyribac *fb* manual weeding. Weed management index, agronomic management index and integrated weed management index were highest under pendimethalin *fb* manual weeding followed by bispyribac, pendimethalin *fb* bispyribac and mechanical weeding. The overall performance index (OP$_i$) was highest under pendimethalin *fb* bispyribac *fb* manual weeding (1.34) followed by oxadiargyl *fb* bispyribac (1.31), pyrazosulfuron *fb* bispyribac (1.18), bispyriac + chlorimuron + metsulfuron (1.14) and bisppyribac (1.12). Weeds reduced the grain yield of rice by 67.1%.

Key words: Chemical control, Direct-seeded rice, Impacts, Herbicide mixtures, Weeds, Weed management, Yield

Dry-seeded rice has been the most promising water saving method wherein the rice is established by direct seeding in non-puddled and non flooded fields. In addition, direct-seeded rice culture requires less labour and capital input with saving of 29% of the total rice production cost. In dry-seeded rice system, dry tillage and aerobic soil conditions are highly conducive for germination and higher growth of weeds which results in greater rice grain yield losses as compared to puddle transplanted rice. It is very often characterized by a complex plurispecific weed flora, composed of grasses, sedges and broad-leaved weeds (Angiras *et al.* 2010, Kumar and Rana 2013, Pavithra and Poonguzhalan 2015). Uncontrolled weeds reduce the yield by 96 to 100% in dry direct-seeded rice (Maity and Mukherjee 2008). Hence, developing an effective weed management approach has been a challenge for widespread adoption of direct-seeded rice cultivation. The rice herbicides used were mainly pre-emergence, which generally do not provide season-long effective weed control. Therefore, need for some alternative post-emergence herbicide which can provide broad-spectrum weed control without affecting direct-seeded rice growth and yield was felt. Post-emergence bispyribac-Na has been recommended as an effective alternative (Kumar and Rana 2013, Kumar *et al.* 2013), if pre-emergence herbicide application is not done. However, in the direct-seeded cultures, weed problem is more severe as they appear in several flushes. In order to optimize weed control efficacy and minimize the application costs, the use of combinations of pre-post-emergence herbicides, formulated or tank mix herbicide mixtures (Rana *et al.* 2015) as well as integrating herbicides with manual or mechanical means (Rana and Angiras 1999a and b) has become the rule rather than the exception. However, any new weed control measure is adopted only when its results are expected to be more economically beneficial than the existing control measure. Growers compare the cost of weed control to select weed control inputs that provide the desired degree of control at the lowest cost. Therefore, present

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investigation was carried out to assess the impacts of new herbicide mixtures in dry seeded rice under mid hill conditions of Himachal Pradesh.

MATERIALS AND METHODS

To study the impact of combinations of herbicides against weed complex in direct-seeded upland rice, a field experiment was conducted during *Kharif* 2013, 2014 and 2015 in randomized block design with 10 treatments and three replications. The treatments were, bispyribac-Na 25 g/ha (20 DAS), pendimethalin 1000 g/ha (pre) *fb* bispyribac 25 g/ha (25 DAS), oxadiargyl 100 g/ha (pre) *fb* bispyribac 25 g/ha (25 DAS), pyrazosulfuron 20 g/ha (pre) *fb* bispyribac 25 g/ha (25 DAS), pendimethalin 1000 g/ha (pre) *fb* bispyribac 25 g/ha (20 DAS) *fb* manual weeding (45 DAS), pendimethalin 1000 g/ha (pre) *fb* manual weeding (25-30 DAS), bispyribac 25 + chlorimuron 20 g/ha + metsulfuron methyl 4 g/ha (20 DAS), cono/rotary weeding (15, 30 and 45 DAS), weed free (manual weeding 15, 30, 45 and 60 DAS) and weedy check. The experimental soil was silty clay loam in texture, acidic in reaction (pH 5.6), medium in available nitrogen (350 kg/ha), phosphorus (22.8 kg/ha) and high in available potassium (211 kg/ha). Rice variety '*HPR 1156*' was sown on 01 June 2013, 20 May 2014 and 25 May 2015 keeping row to row spacing of 25 cm (approximately 80 kg/ha seed rate). The crop was fertilized with 90 kg N, 40 kg P_2O_5 and 40 kg K_2O/ha through urea, single super phosphate and muriate of potash, respectively. The required quantity of half N and whole P_2O_5 and 40 kg K_2O was drilled at sowing. The remaining half N was band placed at 55 DAS. Herbicides were applied with power sprayer using 600 L water per hectare. The rest of the management practices were in accordance with the recommended package of practices. Data on density of weeds was recorded at harvest of crop. The crop was harvested on 22 October 2013, 28 October 2014 and 24 October 2015.

The data obtained were subjected to statistical analysis by analysis of variance (ANOVA) for the randomized block design to test the significance of the overall differences among the treatments by the "F" test and conclusion was drawn at 5% probability level. Standard error of mean was calculated in each case. When the 'F' value from analysis of variance tables was found significant, the critical difference was computed to test the significance of the difference between the two treatments. The economic threshold (=economic injury levels), the weed density at which the cost of treatment equals the economic benefit obtained from that treatment, was calculated after Uygur and Mennan (1995) as well as those given by Stone and Pedigo (1972) as below:

Uygur and Mennan:

$$Y= [\{(100/He*Hc)+A_C\}/(Gp*Yg)]*100$$

Where, Y is per cent yield losses at a different weed density; He, herbicide efficiency; Hc, herbicide cost; Ac, application cost of herbicide; Gp, grain price and Yg, yield of weed free.

Stone and Pedigo:

Economic threshold = Gain threshold/ Regression coefficient

Where, gain threshold = Cost of weed control (Hc+Ac)/Price of produce (Gp), and regression coefficient (b) is the outcome of simple linear relationship between yield (Y) and weed density/ biomass (x), Y = a + bx.

The different impact indices were worked out after Rana and Kumar (2014) as follow:

Additionally, 'overall performance index' was determined, by calculating firstly the 'comparable unit value' where the value under a particular treatment of a parameter was divided by the respective arithmetic mean value of treatments for that parameter as given below:

$$U_{ij} = \frac{V_{ij}}{AM_j}$$

Where U_{ij} is the unit value for ith treatment corresponding to jth parameter, V_{ij} is the actual measured value for ith treatment and jth parameter and A_{Mj} is the arithmetic mean value for jth parameter.

Weed persistence index (WPI)

$$WPI = \frac{Weed\ weight\ in\ treated\ plot}{Weed\ weight\ in\ control\ plot}\ x\ \frac{Weed\ count\ in\ control\ plot}{Weed\ count\ in\ treated\ plot}$$

Crop resistance index (CRI)

$$CRI = \frac{Crop\ weight\ in\ treated\ plot}{Crop\ weight\ in\ control\ plot}\ x\ \frac{Weed\ weight\ in\ control\ plot}{Weed\ weight\ in\ treated\ plot}$$

Weed management index (WMI)

$$WMI = \frac{Percent\ yield\ over\ control}{Percent\ control\ of\ the\ pest}$$

Agronomic management index (AMI)

$$AMI = \frac{Percent\ yield\ over\ control - Percent\ control\ of\ the\ pest}{Percent\ control\ of\ the\ pest\ (weed)}$$

Integrated Management index (IWMI)

$$IWMI = \frac{WMI + AMI}{2}$$

Herbicide efficiency index (EI)

$$EI = \frac{\frac{Yield\ of\ treatment - Yield\ of\ control}{Yield\ of\ control}\ x\ 100}{\frac{Weed\ weight\ in\ treatment}{Weed\ weight\ in\ control}\ x\ 100}$$

Secondly, the overall performance index was calculated as an average of unit values (U_{ij}) of all the parameters under consideration:

$$OP_i = \frac{1}{N}\sum_{i=1}^{N} U_{ij}$$

where OP_i is the overall performance index for ith treatment and N is the number of parameters considered in deriving performance index.

RESULTS AND DISCUSSION

Effect on weeds

The major weeds of the experimental field were *Echinochloa colona* (50, 57.8 and 63.6%), *Digitaria sanguinalis* (5.0, 9.5 and 7.6%), *Panicum dichotomiflorum* (38.0, 12.6 and 14.2%), *Aeschynomene indica* (2.0, 9.7 and 4.1%), *Ageratum conyzoides* (5.0, 5.3 and 3.8%) and *Cyperus iria* (0.0, 5.3 and 6.6% during 2013, 2014 and 2015, respectively in the unweeded check). *Commelina benghalensis* showed its sporadic occurrence.

Weed control treatments brought about significant variation in the count of *Echinochloa colona* during all the three years (Table 1). All weed control treatments were significantly superior to weedy check in reducing *E. colona* in all the three years. Herbicidal treatments behaving similar with weed free resulted in significantly lower density of *E. colona* as compared to three mechanical weedings with cono/rotary weeder. The superiority of bispyribac (Kumar and Rana 2013, Kumar *et al.* 2013) and herbicide combinations (*Shekhar et al.* 2012, Rana *et al.* 2015) in controlling *E. colona* has been reported by several workers. Weed control treatments caused significant variation also in the count of *P. dichotomiflorum* during all the three years of experimentation. Oxadiargyl *fb* bispyribac, pyrazosulfuron *fb* bispyribac, pendimethalin *fb* bispyribac *fb* manual weeding and bispyribac + chlorimuron + metsulfuron-methyl behaving statistically similar resulted in significantly lower density of *P. dichotomiflorum* as compared to weedy check. The other treatments could not significantly curtail the population of *P. dichotomiflorum* over the unweeded check. Weed control treatments resulted in significant variation in the count of *D. sanguinalis* during 2014 and 2015. The population of the weed was completely eliminated under oxadiargyl *fb* bispyribac, pyrazosulfum *fb* bispyribac, pendimethalin *fb* bispyribac *fb* manual weeding, pendimethalin *fb* manual weeding and bispyribac + chlorimuron + metsulfuron methyl. The other treatments either had higher or equal population of this weed as under weedy check.

Weed control treatments encountered significant variation in the count of *A. indica* during 2014 and 2015 (Table 2). All treatments were significantly superior to weedy check in reducing the population of *A. indica* during 2014. All herbicidal treatments except pendimethalin *fb* bispyribac gave comparable control of this weed as weed free. *Ageratum* appeared late in the season by 75 DAS. Its population also varied significantly due to treatments during 2014 and 2015. Its complete elimination was noticed in the treatments bispyribac, pendimethalin *fb* bispyribac *fb* manual weeding and mechanical weeding. In the other treatments its population was

Table 1. Effect of treatments on species wise weed count (no./m²) at harvest in direct-seeded rice

Treatment	Dose (g/ha)	Time (DAS)	*Echinochloa*			*Digitaria*			*Panicum*		
			2013	2014	2015	2013	2014	2015	2013	2014	2015
Bispyribac-Na	*25*	*20*	3.2(9)	3.0(8)	2.6(6)	1.4(1)	1.5(1)	1.7(2)	3.6(12)	3.5(11)	3.39(11)
Pendimethalin *fb* bispyribac	1000, 25	0-2, 25	2.1(4)	2.0(3)	2.1(3)	2.6(6)	2.5(5)	2.7(6)	3.3(10)	3.1(9)	2.88(7)
Oxadiargyl *fb* bispyribac-Na	100, 25	0-2, 25	3.1(8)	3.0(8)	2.9(7)	1.0(0)	1.0(0)	1.0(0)	2.7(6)	1.8(2)	1.76(2)
Pyrazosulfum *fb* bispyribac-Na	20, 25	0-3, 25	2.8(7)	2.7(7)	2.8(7)	1.0(0)	1.0(0)	1.0(0)	2.7(6)	1.8(2)	1.76(2)
Pendimethalin *fb* bispyribac *fb* manual weeding	1000, 25	0-2, 20, 45	2.8(7)	2.7(6)	2.5(5)	1.0(0)	1.0(0)	1.0(0)	2.8(7)	1.8(2)	1.73(2)
Pendimethalin *fb* manual weeding	1000	0-2, 25-30	3.2(9)	2.8(7)	2.8(7)	1.0(0)	1.0(0)	1.0(0)	3.4(11)	3.3(10)	2.88(7)
Bispyribac-Na + (chlorimuron + metsulfuron methyl)	25+ 20+4	20	3.2(9)	3.0(8)	3.0(8)	1.0(0)	1.0(0)	1.0(0)	2.0(3)	1.6(2)	1.58(2)
Cono/ rotary weeding	-	15,30,45	3.7(13)	3.9(14)	3.6(12)	1.8(2)	1.7(2)	1.8 (2)	3.5(11)	1.9(2)	1.48(1)
Weed free	-		2.7(6)	2.7(6)	2.1(3)	1.8(2)	1.7(2)	1.9(3)	3.5(11)	2.0(3)	2.09(3)
Weedy check	-		5.1(25)	4.8(22)	5.1(25)	1.9(3)	2.1(4)	2.0(3)	4.5(19)	2.4(5)	2.56(6)
LSD (P=0.05)			1.7	0.5	0.4	NS	0.6	0.6	1.3	1.0	1.05

Values given in the parentheses are the original means DAS= after sowing *fb*= followed by either equal or more than the weedy check. Weed control treatments resulted in significant variation in the count of *C. iria*. *Cyperus* is sensitive to competition. Its appearance was noticed only under pyrazosulfuron *fb* bispyribac, weed free and weedy. In other treatments it was not noticed. Total weed count was significantly influenced by different weed control treatments (Table 3). All the weed control treatments except three mechanical weedings with cono/rotary weeder behaving statistically similar resulted in significantly lower total weed count. The superiority of herbicidal treatments in curtailing weed population has been presented in several scientific papers (Maity and Mukherjee 2008, Kumar *et al.* 2008, 2011, Shekhar *et al.* 2012, Angiras *et al.* 2010).

Impact of weed control

Rice grain yield was negatively associated with the count of *E. colona* (r= -0.883**, -0.832**, -0.950** and -0.910**, during 2013, 2014, 2015 and combined of all years, respectively; **significant at 1% level of significance), *A. indica* (r= - 0.827** and -0.769** during 2014 and the combined), *P. dichotomiflorum* (r= - 0.730* during 2013 only, *significant at 5% level of significance) and total weed count (r= -0.933**, -0.930**, -0.871** and -0.973**) showing their high competitiveness in rice. The count of rest of the weeds was not significantly associated with grain yield of rice. Weed control treatments resulted in significant variation in grain yield of rice (Table 3). Pendimethalin *fb* bispyribac *fb*

Table 2. Effect of treatments on species wise weed density (no./m^2) at harvest in direct-seeded rice

Treatment	Dose (g/ha)	Time (DAS)	*Aeschynomene*			*Ageratum*			*Cyperus*		
			2013	2014	2015	2013	2014	2015	2013	2014	2015
Bispyribac-Na	*25*	*20*	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Pendimethalin *fb* bispyribac	1000, 25	0-2, 25	1.5(1)	1.5(1)	1.4(1)	1.5(1)	1.4(1)	1.6(1)	1.0(0)	1.0(0)	1.0(0)
Oxadiargyl *fb* bispyribac-Na	100, 25	0-2, 25	1.0(0)	1.0(0)	1.0(0)	1.7(2)	1.7(2)	1.8(2)	1.0(0)	1.0(0)	1.0(0)
Pyrazosulfum *fb* bispyribac-Na	20, 25	0-3, 25	1.0(0)	1.0(0)	1.0(0)	1.8(2)	1.7(2)	1.7(2)	2.1(4)	2.3(4)	1.8(2)
Pendimethalin *fb* bispyribac *fb* manual weeding	1000, 25	0-2, 20, 45	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Pendimethalin *fb* manual weeding	1000	0-2, 25-30	1.5(1)	1.0(0)	1.0(0)	3.5(11)	3.2(9)	2.3(5)	1.0(0)	1.0(0)	1.0(0)
Bispyribac-Na + (chlorimuron + metsulfuron methyl)	25+ 20+4	20	1.0(0)	1.0(0)	1.0(0)	1.7(2)	1.6(2)	2.0(3)	1.0(0)	1.0(0)	1.0(0)
Cono/ rotary weeding	-	15,30,45	1.5(1)	1.4(1)	1.5(1)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weed free	-		1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.5(1)	1.5(1)	2.0(3)	1.9(3)	1.9(3)
Weedy check	-		1.4(1)	2.2(4)	1.61(2)	1.9(3)	1.7(2)	1.6(2)	1.0(0)	1.7(2)	1.9(3)
LSD (P=0.05)			NS	0.3	0.25	NS	0.4	0.3	0.7	0.5	0.5

Values given in the parentheses are the original means DAS=days after sowing *fb*= followed by

Table 3. Effect of different treatments on total weed count (no./m^2), grain yield, economic thresholds and economics in direct-seeded rice

Treatment	Dose (g/ha)	Time (DAS)	Weed count (no/m^2)			Grain yield (t/ha)			Gt	Et		CWC	NRwc	MBCR
			2013	2014	2015	2013	2014	2015		SP	UM			
Bispyribac-Na	*25*	*20*	4.8(22)	4.8(22)	4.4 (18)	2.79	2.68	2.61	156	2.5	5.9	2340	34036	14.55
Pendimethalin *fb* bispyribac-Na	1000, 25	0-2, 25	4.8(22)	4.6(20)	4.2(16)	3.03	2.80	2.68	301	4.8	11.0	4520	35002	7.74
Oxadiargyl *fb* bispyribac-Na	100, 25	0-2, 25	4.2(17)	3.8(14)	3.5 (11)	3.09	3.07	2.62	222	3.6	8.3	3326	38107	11.46
Pyrazosulfum *fb* bispyribac	20, 25	0-3, 25	4.4(19)	4.3(17)	3.8(13)	2.80	2.81	2.31	239	3.8	9.0	3580	31626	8.83
Pendimethalin *fb* bispyribac *fb* manual weeding	1000, 25	0-2, 20, 45	3.9(14)	3.2(10)	2.9 (7)	3.15	3.38	2.79	539	8.6	18.1	8090	37338	4.62
Pendimethalin *fb* manual weeding	1000	0-2, 25-30	5.7(32)	5.3(27)	4.4 (19)	1.96	2.21	2.39	542	8.7	18.5	8130	17203	2.12
Bispyribac-Na + chlorimuron + metsulfuron methyl	25+ 20+4	20	3.8(14)	5.3(27)	3.7(13)	2.65	2.60	2.32	271	4.3	9.4	4062	28609	7.04
Cono/rotary weeding	-	15, 30, 45	5.3(27)	4.2(16)	5.2 (27)	2.23	2.40	2.21	782	12.5	25.1	11730	15688	1.34
Weed free	-	-	4.8(22)	4.1(16)	4.3(17)	2.80	2.81	2.43	1111	17.8	35.7	16660	19411	1.17
Weedy check	-	-	7.1(50)	6.6(44)	6.1(37)	1.12	1.08	0.87	-	-	-	-	-	-
LSD (P=0.05)	-	-	2.0	2.1	2.0	0.37	0.31	0.25	-	-	-	-	-	-

Values given in the parentheses are the original means, DAS= Days after sowing, *fb*= Followed by; Gt= Gain threshold; Et= Economic threshold; SP= After Stone and Pedigo (1972); UM= After Uygur & Mennan (1995); CWC= Cost of weed control (INR/ha); NR_{WC} = net return due to weed control (INR/ha); MBCR= Marginal benefit cost ratio manual weeding 1000 *fb* 25g/ha (0-2 *fb* 20 DAS *fb* 45 DAS) behaving statistically alike with oxadiargyl *fb* bispyribac, pendimethalin *fb* bispyribac, bispyribac, pyrazosulfuron *fb* bispyribac and weed free during 2014 and 2015 resulted in significantly higher grain yield of rice over other treatments. The higher grain yield under these treatments was owed to superior weed control. These findings were in line with those of Angiras *et al*. (2010), Rana and Angiras (1999a&b), Kumar *et al.* (2008, 2011, 2013), Kumar and Rana (2013), Shekhar *et al*. 2012) and Maity and Mukherjee (2008). Weeds in unweeded check reduced the grain yield of paddy by 67.1% over pendimethalin *fb* bispyribac *fb* manual weeding.

The linear relationship between weed count (x) and grain yield (Y) of direct seeded rice is given here as under,

$$Y= 3799 – 62.4x \qquad (R^2= 0.947)\ldots\ldots(i)$$

The equation (i) explains that 94.7% of variation in grain yield of dry seeded rice due to weed count could be explained by the regression equation. With every 1 weed/m^2 increase in density, the grain yield of dry seeded rice was expected to fall by 62.4 kg/ha.

The economic threshold levels of weeds at the current prices of treatment application and the crop production on the basis of weed infestation in direct-seeded rice are given in Table 3. The economic threshold levels (no/m^2) with the weed management practices studied varied between 2.5-17.8/m^2 when determined after Pedigo and Stone (1972) and 5.9-35.7/m^2 after Uygur and Mennan (1995). Though the later method determined higher values of economic threshold than the former, the trend was almost similar under the methods of determination (r= 0.9995**, significant at 1% level of significance). It is clearly indicated that any increase in the cost of treatment would lead to higher values of economic threshold, whereas an increase in price of crop produce would result in lowering the economic threshold. Manual weeding engaged more labour and had higher cost tending to increase the economic threshold more than the herbicidal treatments.

Weed management cost was highest under weed free followed by mechanical weeding. Cost of weed control under herbicidal/integrated treatments was 14-48.8% of weed free and 19.9-69.3% of that under mechanical weeding. Bispyribac 25 g/ha had lowest cost of weed management followed by oxadiargyl *fb* bispyribac. Due to lower cost of weed management, all herbicidal treatments gave more net return due to weed control over mechanical weeding. Oxadiargy *fb* bispyribac resulted in highest net return due to weed control followed by pendimethalin *fb* bispyribac *fb* manual weeding, pendimethalin *fb* bispyribac, bispyribac and pyrazosulfuron *fb* bispyribac. All herbicidal/integrated weed management treatments resulted in higher MBCR over mechanical weeding and weed free. MBCR was highest under bispyribac followed by oxadiargyl *fb* bispyribac, pyrazosulfuron *fb* bispyribac, pendimethalin *fb* bispyribac and bispyribac + chlorimuron + metsulfuron methyl.

Weed free had highest weed control efficiency followed by pendimethalin *fb* bispyribac *fb* manual weeding and pendimethalin *fb* bispyribac. Weed persistence index was highest under weed free followed by pendimethalin *fb* bispyribac and pendimethalin *fb* manual weeding. Crop resistance index was highest under pendimethalin *fb* bispyribac *fb* manual weeding. This was followed by oxadiargyl *fb* bispyribac, pyrazosulfuron *fb* bispyribac, weed free and pendimethalin *fb* bispyribac. Efficiency index indicates weed killing potential and

Table 4. Impact assessment indices

Treatment	Dose (g/ha)	Time (DAS)	WCE	WPI	CRI	EI	WI	WMI	AMI	IWMI	OP_i
Bispyribac-Na	25	20	74.7	1.90	5.47	3.39	-0.5	5.07	4.07	4.57	1.12
Pendimethalin *fb* bispyribac	1000, 25	0-2, 25	82.2	2.50	6.20	3.97	-5.9	5.01	4.01	4.51	1.09
Oxadiargyl *fb* bispyribac-Na	100, 25	0-2, 25	74.6	1.25	8.97	5.83	-9.2	4.19	3.19	3.69	1.31
Pyrazosulfum *fb* bispyribac-Na	20, 25	0-3, 25	75.1	1.51	6.85	4.19	1.5	4.14	3.14	3.64	1.18
Pendimethalin *fb* bispyribac *fb* manual weeding	1000, 25	0-2, 20, 45	82.5	1.33	12.99	8.71	-16.0	3.96	2.96	3.46	1.34
Pendimethalin *fb* manual weeding	1000	0-2, 25-30	73.3	2.22	3.61	1.92	18.4	5.23	4.23	4.73	0.85
Bispyribac-Na + chlorimuron + metsulfuron methyl	25+ 20+4	20	75.5	1.66	6.05	3.60	5.8	4.16	3.16	3.66	1.14
Cono/rotary weeder	-	15,30,45	32.9	0.80	4.16	2.29	14.8	4.81	3.81	4.31	0.84
Weed free	-		84.5	2.70	6.23	3.85	0.0	4.51	3.51	4.01	1.03
Weedy check	-		74.7	1.00	1.00	0.00	61.8	0	0	0	0.10
LSD (P=0.05)			-	-	-	-	-	-	-	-	-

Values given in the parentheses are the original means, DAS= Days after sowing, *fb*= Followed by ; WCE= Weed control efficiency (%); WPI= Weed persistence index; CRI= Crop resistance index; EI= Efficiency index; WI= Weed index; WMI= Weed management index; AMI= Agronomic management index; IWMI= Integrated weed management index; OP_i = overall performance index phytotoxicity on crop followed the trend similar to crop resistance index and was highest under pendimethalin *fb* bispyribac *fb* manual weeding. This was followed by oxadiargyl *fb* bispyribac, pyrazosulfuron *fb* bispyribac and pendimethalin *fb* bispyribac. Weed index indicates fall in yield over a weed free was minimum under pendimethalin *fb* bispyribac *fb* manual weeding followed by oxadiargyl *fb* bispyribac, pendimethalin *fb* bispyribac and bispyribac. The other treatments had positive weed index indicating poor performance than the weed free. WMI, AMI and IWMI were highest under pendimethalin *fb* manual weeding followed by bispyribac, pendimethalin *fb* bispyribac and mechanical weeding. Since the treatments under the impact assessment indices discussed above were less consistent in performance, an overall 'performance index' considering various indices as well as percent control of major weeds, yield and economics was drawn to have a valid inference. The overall performance index (OP_i) was highest under pendimethalin *fb* bispyribac *fb* manual weeding (1.34) followed by oxadiargyl *fb* bispyribac (1.31), pyrazosulfuron *fb* bispyribac (1.18), bispyriac + chlorimuron + metsulfuron (1.14), bisppyribac (1.12), pendimethalin *fb* bispyribac (1.09) and weed free (1.03). Thus in order of preference, pendimethalin 1000 g/ha (pre) *fb* bispyribac 25 g/ha (25 DAS) *fb* manual weeding (45 DAS), oxadiargyl 100 g/ha (pre) *fb* bispyribac 25 g/ha (25 DAS), pyrazosulfuron 20 g/ha (pre) *fb* bispyribac 25 g/ha (25 DAS), bispyriac 25 g/ha + chlorimuron 20 g/ha + metsulfuron 4 g/ha (20 DAS), bisppyribac 25 g/ha (20 DAS), pendimethalin 1000 g/ha (pre) *fb* bispyribac 25 g/ha (25 DAS) may be recommended for an effective weed management in direct seeded rice.

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Effective post-emergence herbicides for weed control in rice nurseries

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ABSTRACT

On farm experiments were conducted during *Kharif* seasons of 2011 and 2012 to study efficacy of post-emergence herbicides bispyribac-sodium 25 g/ha for broad-spectrum weed control in rice nursery. Among the different treatments, post-emergence application of bispyribac-sodium 25 g/ha applied at 15 DAS (days after sowing) significantly reduced total weed density with weed control efficiency of 90.9 to 97.6% for *Echinochloa crus-galli*, *Trianthema portulacastrum* and *Cyperus iria*. Among other treatments, pre-emergence application of pretilachlor + safener 0.15 kg/ha also recorded significantly lower weed density as compared to control (unweeded). Although weed control efficiency of this treatment was relatively higher for *E. crus-galli* (84.7%) but for *T. portulacastrum* and *C. iria*, this treatment recorded weed control efficiency of 75.9 and 71.2%, respectively. Farmers practice (increased seed rate 100 g/m^2) also recoded significantly lower weed density as compared to control (unweeded) but the weed control efficiency was quite low against *E. crus-galli* (36.8%) and *C. iria* (28.1%); however, it was relatively higher for *T. portulacastrum* (66.0%) with mean of 43.7%.

Key words: Bispyribac-sodium, Post-emergence herbicides, Rice Nursery, Sedges, Weed

Rice is an important summer crop of Punjab grown over an area of 28.9 lakh hectares. mostly crop is raised by puddle transplanting. Approximately one lakh hectares of rice nursery is raised for transplanting the above area in the state. Organic manures like farm yard manure are used for raising rice nursery and saturated conditions are maintained throughout (Anonymous 2016). These conditions are very favorable for germination and establishment of the weed. These weeds compete with the nursery plants and results in poor rice transplants. If not controlled, these weed seedlings are transplanted along with rice seedlings and these grown up weed plants compete with crop plants and result in more than 50% reduction in crop yields causing big financial loss to the growers (Walia *et al*. 2005). Hence, in transplanted rice cultivation, maintenance of weed free nursery is a pre-requisite, in order to ensure good seedling vigour and ultimately optimum stand in rice and also to reduce early weed competition in main field. The farmers use pre-emergence herbicides, *viz*. butachlor, thiobencarb and pretilachlor which are effective only against grassy weeds like *Echinochloa crus-galli* and *E. colona*. Sedge weeds such as *Cyperus iria* and *C. difformis* and broad-leaf weeds like *Trianthema portulacastrum* are not controlled with these chemicals and hence the left over weeds pose severe competition to tender nursery. Thus, there is an urgent need for some post-emergence herbicide which can be used as need based tool to tackle the complex weed flora of rice nurseries. In past, several workers reported about the possible use of pre- and post-emergence herbicides in rice nurseries (Narasimha-Reddy *et al.* 1999, Venkataraman 2000, Rao 2005). Hence, on farm investigations were planned with the objective to evaluate the bio-efficacy of post-emergence herbicide bispyribac-sodium against complex weed flora of paddy nurseries.

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MATERIALS AND METHODS

On farm trials to study the efficacy of post-emergence herbicide bispyribac-sodium 25 g/ha were conducted for two consecutive seasons at two locations in districts Faridkot (*Kharif* 2011) and Moga (*Kharif* 2012) of Punjab. The details of conduct and address of farmers selected for conducting trials are given (Table 1).

The soil of experimental fields was sandy loam in texture during both the years. Soil rated low in available nitrogen during 2011 but was medium during 2012. However, available phosphorus and potassium status of the soils were high during both the years. Rice nursery was fertilized with 60 kg/ha nitrogen, 25 kg/ha of phosphorus and 100 kg/ha of zinc sulphate (21%) besides the application of 25 t/ha of FYM. The treatments included the pre-emergence

Table 1. Details of location, variety and sowing date of trials during *Kharif* 2011 and 2012

Name and Address of farmer	Variety	Date of sowing
Sh. Gagan Bajaj, Machaki Road, Faridkot	PR 116	12 May, 2011
Sh. Gurvinder Singh, Talwandi Road, Faridkot	PR 116	16 May 2011
KVK Farm, Budh Singh Wala (Moga)	Pusa Basmati 1121	2 June 2012
Sh.Gurpreet Singh Village Tare wala (Moga)	Pusa basmati 1121	3 June 2012

application of pretilachlor + safener 0.15 kg/ha (standard), post-emergence application of bispyribac-sodium 25 g/ha, farmers practice (increased seed rate 100 g/m^2) and unweeded (control). However, during *Kharif* 2011, only two treatments *i.e.* post-emergence application of bispyribac-sodium 25 g/ha and unweeded (control) were evaluated. The herbicide (bispyribac-sodium) was sprayed 15 days after sowing of rice nurseries. The herbicide was sprayed with knapsack sprayer using flat fan nozzle with 375 litres of water per hectare. Application of pre-emergence herbicide was made within 48 hours of sowing of rice nursery by broadcasting after mixing in 60 kg of sand per hectare in standing water.

Data on weed count was recorded from two randomly selected spots per plot by using a quadrate measuring 50 x 50 cm. Weed count data were taken before herbicide spray and also 15 days after spraying the post- emergence herbicide. Weed control efficiency was calculated as given below:

Weed control efficiency (%) = (weed count in control plot-weed count in treatment plot/ weed count in control plot) x 100

Statistical analysis of data was done using SAS 9.1 software packages. To test the significance of means, t-test was used during 2011; however, the ANOVA was worked out in RCBD design during 2012.

RESULTS AND DISCUSSION

Effect on weeds

The population of *Echinochloa crus-galli*, *Trianthema portulacastrum* and *Cyperus iria* recorded in randomly selected spots at 14 DAS ranged between 15-18, 9-11and 7.5-11 plants/m^2, respectively during 2011; and 8-11, 3-7 and 9-12 plants/m^2, respectively during 2012 in the plots allocated to unweeded control and bispyribac sodium treatments. However, plots treated with pre-emergence application of pretilachlor + safener 0.15 kg/ha (standard) recorded the population ranging between 1.5-2.0, 1.0-1.5, 2.5-3.0 plants/m^2, respectively and farmers practice (*i.e.* increasing seed rate) recorded the population ranging between 4.0-4.5, 1.0-1.5 and 2.0-4.0 plants/m^2, respectively of *Echinochloa crus-galli*, *Trianthema portula-castrum* and *Cyperus iria*. The less weed population under the treatment of pretilachlor + safener 0.15 kg/ha (pre-emergence) and farmers practice as compared to control may be ascribed to the effect of pre-emergence herbicides as well as the role of high seed rate in smothering of weeds.

Data (Table 3) indicated that all the weed control treatments resulted in significant reduction in weed density as compared to unweeded control. Pretilachlor + safener 0.15 kg/ha and farmers practice resulted in significant reduction in weeds as compared to control but were significantly poor as compared to post-emergence application of bispyribac-sodium 25 g/ha, which was highly effective in controlling complex weed flora of rice nurseries during both the years of study as is evident from significant reduction in weed density as compared to unweeded control and other weed control treatments. Bispyribac-sodium 25 g/ha resulted in effective control of all weeds and recorded weed control efficiency of 97.6, 92.3 and 90.9% during *Kharif* 2011 and 95.0, 91.8 and 94.6% during *Kharif* 2012 against *E. crus-galli*, *T. portulacastrum*,

Table 2. Weed density before the application of post-emergence herbicide (14 DAS) in rice nurseries

Treatment	Weed density (no./m^2)							
	Kharif 2011				*Kharif* 2012			
	E. crus-galli	*T. portulacastrum*	*C. iria*	Total weed count	*E. crus-galli*	*T. portulacastrum*	*C. iria*	Total weed count
Pretilachlor + safener 0.15 kg/ha (pre-emergence)	-	-	-	-	1.25	1.25	2.75	5.25
Bispyribac-sodium 25 g/ha (post-emergence)	16.5	10.5	9.0	36.0	10.0	3.75	9.5	23.25
Farmers practice (increased seed rate - 100 g/m^2)	-	-	-	-	4.25	1.25	3.0	8.50
Unweeded control	17.0	9.5	8.25	34.75	9.25	5.75	10.75	25.75
t-test significance/ LSD (P=0.05)	NS	NS	NS	NS	1.95	2.47	2.36	3.29

Table 3. Weed density after the application of post-emergence herbicide (30 DAS) in rice nurseries

Treatment	Weed density (no./m^2)							
	Kharif 2011				*Kharif* 2012			
	E. crus-galli	*T. portulacastrum*	*C. iria*	Total weed count	*E. crus-galli*	*T. portulacastrum*	*C. iria*	Total weed count
Pretilachlor + safener 0.15 kg/ha (pre-emergence)	-	-	-	-	2.25	5.0	4.0	11.25
Bispyribac-sodium 25 g/ha (post-emergence)	0.5	1.0	1.0	2.5	1.25	1.0	0.75	2.50
Farmers practice (Increased seed rate- 100 g/m^2)	-	-	-		9.0	3.75	10.0	22.75
Unweeded control	23.0	17.0	13.0	53.0	14.75	11.5	14.0	40.25
t-test significance/ LSD	**	**	**	**	2.65	1.88	1.65	6.12

** significant at 1% ; LSD value at 5%

Table 4. Weed control efficiency (WCE) of different treatments in rice nurseries

Treatment	Weed control efficiency (%)								Average of two years
	Kharif 2011				*Kharif* 2012				
	E. crus-galli	*T. portulacastrum*	*C. iria*	Mean WCE	*E. crus-galli*	*T. portulacastrum*	*C. iria*	Mean WCE	
Pretilachlor + safener 0.15 kg/ha	-	-	-	-	84.7	75.9	71.3	77.3	77.3
Bispyribac-sodium 25 g/ha	97.6	92.3	90.9	93.6	95.0	91.8	94.6	93.8	93.7
Farmers practice (Increased seed rate-100 g/m^2)	-	-	-		36.9	66.0	28.1	43.7	43.7
Unweeded control	-	-	-	-	-	-	-	-	

C. iria, respectively (Table 4).The pre-emergence application of pretilachlor + safener 0.15 kg/ha also recorded significantly lower weed density as compared to control. Although the weed control efficiency of this treatment is relatively higher for *E. crus-galli* (84.7%) but for T. *portulacastrum* and *C. iria,* this treatment recorded weed control efficiency of 75.9 and 71.2%, respectively. Farmers practice (increased seed rate 100 g/m^2) also recorded significantly lower weed density as compared to control but the weed control efficiency was quite low against *E. crus-galli* (36.6%) and *C. iria* (28.1%) but relatively higher for *T. portulacastrum* (66.0%). Apparently, increasing seed rate is an effective method to reduce the weed density of *T. portulacastrum.* These results corroborate the earlier findings of Rao and Ratnam (2010).

Effect on crop

The visual observation at 7 and 14 days after spray of post-emergence herbicide revealed no phytotoxicity of herbicide on rice nurseries.

It was concluded that post-emergence application of bispyribac-sodium 25 g/ha applied at 15 DAS is very effective due to its effective broad-spectrum weed control and high selectiveness to rice nursery without any phytotoxicity.

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Herbicides for weed management in direct dry-seeded rice

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ABSTRACT

A field experiment was conducted during *Kharif* seasons of 2010 and 2011 to evaluate the efficacy of different herbicides and their combinations in managing weeds of direct dry-seeded rice. The major weeds were *Echinochloa colona, Echinochloa crus*-galli, *Leptochloa chinensis* among grasses, *Caesulia axillaris* and *Trianthema monogyna* among broad-leaved weeds and *Cyperus rotundus* among sedge. The lowest total weed density was recorded with azimsulfuron 35 g/ha and cyhalofop-butyl + ready mix of chlorimuron + metsulfuron 60 + 20 g/ha, which were at par with each other followed by fenoxaprop + ethoxysulfuron 60 + 15 g/ha and twice hand weeding at 20 and 40 days after seeding (DAS). The lowest weed biomass was recorded with combined application of fenoxaprop + ethoxysulfuron 60 + 15 g/ha and fenoxaprop + ready mix of chlorimuron + metsulfuron 60 + 20 g/ha. The highest weed control efficiency was recorded with twice hand weeding at 20 and 40 DAS (89.9%) followed by fenoxaprop + ethoxysulfuron 60 + 15 g/ha, fenoxaprop + ready mix of chlorimuron + metsulfuron 60 + 20 g/ha, bispyribac-sodium 25 g/ha and fenoxaprop 60 g/ha over the weedy check. The higher grain yield (3.50 t/ha) was recorded with twice hand weeding (20 and 40 DAS), which was at par with fenoxaprop + ethoxysulfuron 60 + 15 g/ha followed by bispyribac-sodium 25 g/ha alone and fenoxaprop + ready mix of chlorimuron + metsulfuron 60 + 20 g/ha.

Key words: Chemical control, Direct dry-seeded rice, Grain yield, Herbicides, Weed control

Rice (*Oryza sativa* L.) is major food grain crop of the world and more than half of the population subsists on it. India is the second largest rice producing country in the world. Rice used to be predominantly grown by transplanting in puddled soil with continuous flooding (Sanches 1973). However, it deteriorates soil physical properties, which adversely affects the growth and productivity of succeeding wheat crop. The increasing cost of labour threatens the sustainability of transplanted rice within the rice-wheat system of Indo-Gangetic Plains. Direct-seeding is cost effective, can save water through rice crop establishment and allows early sowing of wheat (Ladha *et al.* 2003). All these factors have increased the interest of farmers to shift from the conventional practice of puddled transplanting to direct-seeded rice (DSR) especially dry-DSR. In dry direct-seeded rice (dry-DSR), dry seed is drilled into the non-puddled soil. Dry-DSR saves irrigation water by 12-35%, labour up to 60% and provides higher net returns (US$ 30-50/ha) with similar or slightly lower yield of rice (Kumar and Ladha 2011). Despite multiple benefits of dry-DSR, weed control remains one of the major challenges for its success (Kumar and Ladha 2011, Rao *et al*. 2007, Singh *et al*. 2008). Weed control is more difficult in dry-DSR than transplanted rice because of simultaneous emergence of both rice and weed seedlings in dry–DSR (Rao *et al*. 2007, Kumar and Ladha 2011). Post-emergence herbicides are used in DSR system for the selective control of weeds. The application of a single post-emergence herbicide in DSR systems often provides suboptimal weed control because of complex weed flora and long critical period of weed control (up to the first 5 to 7 weeks after crop establishment) (Khaliq *et al.* 2011, Awan *et al.* 2015). A single pre-emergence herbicide or a single post-emergence herbicide hardly provides satisfactory yield in DSR systems mainly because of the narrow spectrum of herbicide activity (Suria *et al.* 2011, Chauhan and Opena 2012). Therefore, the better weed control option in dry-DSR systems was found to be the applications of pre-emergence herbicide followed by (*fb*) a post-emergence herbicide or a mixture of post-emergence herbicides *fb* one hand weeding (Mahajan and Timsina 2011, Chauhan and Opena 2012). The objective of this study was to evaluate the herbicides and their combinations for effective management of grassy, broad-leaf weeds and sedges without the need for hand weeding.

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MATERIALS AND METHODS

A field experiment was conducted during *Kharif* season of 2010 and 2011 at N.E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture

& Technology Pantnagar, U.S. Nagar, Uttarakhand to evaluate the efficacy of pre- and post-emergence herbicides and their combinations in weed control in dry-DSR. The soil of experimental plot was silty clay loam in texture, medium in organic carbon (0.66%), available phosphorus (27.5 kg/ha) and potassium (243.5 kg/ha) with pH 7.3. The experiment was laid out in randomized block design with three replications. The treatments consisted of pyrazosulfuron 25 g/ha, pretilachlor 750 g/ha, cyhalofop-butyl 90 g/ha, fenoxaprop 60 g/ha, cyhalofop-butyl + ready mix of chlorimuron + metsulfuron 90 +20 g/ha, fenoxaprop + ready mix of chlorimuron + metsulfuron 60 + 20 g/ha, azimsulfuron 35 g/ha, bispyribac sodium 25 g/ha, tank mix of fenoxaprop + ethoxysulfuron 60 + 15 g/ha, oxyflurofen + 2,4-D 300 + 500 g/ha, twice hand weeding at 20 and 40 days after seeding (DAS) and weedy check. Rice variety "*Sarjoo 52*" was sown at row spacing of 20 cm on June 09, 2010 and June 14, 2011. Herbicides were sprayed with flat fan nozzle with 750 litres volume of water per hectare using knapsack sprayer. The observations on density and dry matter weight of weeds were taken at 30 and 60 DAS. Dry matter of weeds was recorded and expressed in g/m^2. The data on weed density and weed dry matter were analyzed after subjecting to square root transformation by adding 1.0 to original values prior to statistical analysis. Yield attributing characters and yield were recorded at harvest. Each experimental plot was threshed by rice thresher to determine grain yield and it is presented as t/ha.

RESULTS AND DISCUSSION

Effect on weeds

Common weed species infesting the experimental site during both the years were *Echinochloa colona, Echinochloa crus-galli* and *Leptochloa chinensis* among grasses, *Caesulia axillaris*, and *Trianthema monogyna* among broad-leaved weeds and *Cyperus rotundus* among sedge. Among different categories of weeds, sedges recorded in higher number followed by grassy and broad-leaved weeds at 30 and 60 DAS during 2010 and 2011, respectively. The density of weed was significantly influenced by weed control treatments in both the years at 30 and 60 DAS. The highest weed infestations were recorded in weedy check plot. All herbicides reduced the growth of weeds compared to those observed in weedy check plots.

At 30 DAS, sole application of fenoxaprop 60 g/ha caused significant reduction in the density of grassy weeds, *viz*. *E. colona*, *E. crus-galli* and *L. chinensis,* which was found at par with twice hand weeding at 20 and 40 DAS and fenoxaprop + ethoxysulfuron 60 + 15 g/ha (Table 1). The control of broad-leaved weeds was total with bispyribac-sodium 25 g/ha and fenoxaprop + ethoxysulfuron 60 + 15 g/ha and these treatments were statistically at par with azimsulfuron 35 g/ha and fenoxaprop 60 g/ha. Lowest population of *C. rotundus* was recorded with hand weeding at twice 20 and 40 DAS. Among the herbicidal treatments, combined application of

Table 1. Effect of different treatments on weed density and weed biomass in direct dry-seeded rice at 30 DAS (pooled data of 2010 and 2011)

Treatment	Weed density (no./m^2)			Total weed density (no./m^2)	Weed biomass (g/m^2)
	Grasses	Broad-leaved weeds	Sedges		
Pyrazosulfuron 25 g/ha (4 DAS)	11.3 (127.3)	2.0 (4.0)	9.2 (98.0)	15.0 (229.3)	7.5 (64.2)
Pretilachlor 750 g/ha (4 DAS)	7.3 (50.0)	2.2 (5.3)	11.9 (177.3)	14.4 (232.7)	8.1 (80.0)
Cyhalofop-butyl 90 g/ha (30 DAS)	9.3 (58.3)	1.6 (2.0)	13.7 (244.0)	17.3 (329.3)	6.4 (48.4)
Fenoxaprop 60 g/ha (30 DAS)	2.8 (7.3)	1.7 (2.7)	12.8 (202.0)	13.4 (212.0)	5.4 (34.1)
Cyhalofop-butyl + (chlorimuron + metsulfuron) 90 + 20 g/ha (30 DAS)	7.9 (64.0)	2.9 (3.3)	4.0 (15.3)	9.0 (82.7)	6.2 (45.5)
Fenoxaprop + (chlorimuron + metsulfuron) 60 + 20g/ha (30 DAS)	5.1 (26.0)	1.9 (3.3)	7.1 (49.3)	8.9 (78.7)	4.6 (21.6)
Azimsulfuron (50 % WP) 35g/ha (20 DAS)	5.2 (30.0)	1.6 (2.0)	9.7 (124.0)	11.2 (156.0)	5.9 (48.3)
Bispyribac- sodium 25 g/ha (20 DAS)	4.7 (26.0)	1.0 (0.0)	4.9 (24.0)	6.8 (50.0)	4.3 (22.0)
Fenoxaprop+ ethoxysulfuron g/ha (30 DAS)	3.5 (12.0)	1.0 (0.0)	6.6 (42.7)	7.4 (54.7)	4.5 (23.1)
Oxyflurofen +2,4-D 300+500 g/ha (4 *fb* 30 DAS)	8.4 (72.7)	1.2 (0.7)	9.3 (89.3)	12.6 (162.7)	6.4 (49.3)
Two hand weedings of 20 and 40 DAS	3.4 (14.7)	2.0 (4.0)	3.6 (12.0)	5.4 (30.7)	3.2 (10.8)
Weedy	10.7 (114.7)	4.6 (20.7)	8.5 (73.3)	14.3 (205.3)	12.2 (179.3)
LSD (P=0.05)	1.8	0.8	3.7	3.4	1.6

Values within parentheses are original. Data are subjected to square root transformation $(\sqrt{x+1})$; DAS = days after seeding

Table 2. Effect of different treatments on weed density and weed biomass in direct dry seeded rice at 60 DAS (pooled data of 2010 and 2011)

Treatment	Weed density (no./m^2) Grasses	Broad-leaved weeds	Sedges	Total weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)
Pyrazosulfuron 25 g/ha (4 DAS)	7.4 (54.0)	1.2 (0.7)	5.4 (35.3)	9.5 (90.0)	18.0 (323.5)	34.8
Pretilachlor 750 g/ha (4 DAS)	5.8 (33.3)	1.2 (0.7)	9.0 (90.7)	11.2 (124.7)	17.4 (303.8)	38.8
Cyhalofop-butyl 90 g/ha (30 DAS)	5.4 (28.7)	1.2 (0.7)	12.8 (168.7)	14.0 (198.1)	15.2 (241.1)	51.4
Fenoxaprop 60 g/ha (30 DAS)	5.3 (27.3)	2.1 (4.7)	11.2 (135.3)	13.0 (167.3)	11.3 (126.1)	74.6
Cyhalofop-butyl + (chlorimuron + metsulfuron) 90 + 20 g/ha (30 DAS)	2.7 (7.3)	1.4 (1.3)	5.2 (28.0)	6.0 (36.6)	14.1 (203.6)	58.9
Fenoxaprop + (chlorimuron + metsulfuron) 60 + 20g/ha (30 DAS)	7.0 (49.3)	1.0 (0.0)	6.6 (46.7)	9.8 (96.0)	7.9 (60.9)	87.7
Azimsulfuron (50 % WP) 35 g/ha (20 DAS)	4.8 (22.7)	1.0 (0.0)	1.2 (0.7)	4.9 (23.4)	11.5 (141.0)	71.6
Bispyribac- sodium 25 g/ha (20 DAS)	4.2 (17.3)	1.0 (0.0)	7.5 (60.7)	8.6 (78.0)	9.4 (89.1)	82.1
Fenoxaprop + Ethoxysulfuron g/ha (30 DAS)	3.1 (9.3)	1.0 (0.0)	7.7 (58.7)	8.3 (68.0)	7.1 (51.3)	89.7
Oxyflurofen + 2,4-D 300 + 500 g/ha (4 *fb* 30 DAS)	7.1 (49.3)	1.0 (0.0)	6.9 (52.7)	10.1 (102.0)	15.8 (255.8)	48.5
Two hand weedings of 20 and 40 DAS	4.7 (21.3)	1.2 (0.7)	4.7 (25.3)	6.9 (47.3)	6.9 (50.3)	89.9
Weedy	7.6 (56.7)	3.4 (11.3)	13.3 (176.0)	15.5 (241.3)	22.3 (496.4)	-
LSD (P=0.05)	1.0	0.6	2.7	2.3	1.6	-

Values within parentheses are original. Data are subjected to square root transformation $(\sqrt{x+1})$; DAS = days after seeding

cyhalofop-butyl + ready mix of chlorimuron + metsulfuron 90 + 20 g/ha and bispyribac sodium 25 g/ha followed by fenoxaprop + ethoxysulfuron 60 + 15 g/ha and fenoxaprop + ready mix of chlorimuron + metsulfuron 90 + 20 g/ha, which were at par with each other. The lowest total weed density was recorded with hand weeding twice at 20 and 40 DAS, which was at par with bispyribac-sodium 25 g/ha and fenoxaprop + ethoxysulfuron 60 + 15 g/ha followed by fenoxaprop + ready mix of chlorimuron + metsulfuron 90 + 20 g/ha and cyhalofop-butyl + ready mix of chlorimuron + metsulfuron 90 + 20 g/ha. Among herbicidal treatments, lowest weed biomass was recorded with bispyribac-sodium 25 g/ha, which was statistically at par with fenoxaprop + ethoxysulfuron 60 + 15 g/ha, fenoxaprop + ready mix of chlorimuron + metsulfuron 90+20 g/ha and fenoxaprop 60 g/ha. These findings were in conformity with Brar and Bhullar (2012).

At 60 DAS, all the herbicidal treatments significantly reduced the density of weeds, broad-leaved weeds and sedges compared to weedy check (Table 2). Density of grassy weeds was significantly reduced by the combination of cyhalofop + ready mix of chlorimuron + metsulfuron 90 + 20 g/ha, which was at par with fenoxaprop + ethoxysulfuron 60 + 15 g/ha. Significant reduction in the density of sedges was recorded with sole application of azimsulfuron 35 g/ha. Total weed density was effectively reduced by azimsulfuron 35 g/ha and cyhalofop butyl + ready mix of chlorimuron + metsulfuron 60 + 20 g/ha, which were at par with each other followed by fenoxaprop + ethoxysulfuron 60 + 15 g/ha, bispyribac-sodium 25 g/ha and twice hand weeding at 20 and 40 DAS than other herbicidal treatments. The lowest weed biomass was recorded with twice hand weeding, which was at par with combined application of fenoxaprop + ethoxysulfuron 60 + 15 g/ha and fenoxaprop + ready mix of chlorimuron + metsulfuron 60 + 20 g/ha followed by bispyribac-sodium 25 g/ha and fenoxaprop 60 g/ha. The highest

Table 3. Effect of different treatments on yield and yield attributing characters of direct dry-seeded rice (pooled data of 2010 and 2011)

Treatment	Panicles (no./m^2)	Grains/ panicle	Grain yield (t/ha)
Pyrazosulfuron 25 g/ha (4 DAS)	48.0	135.0	0.59
Pretilachlor 750 g/ha (4 DAS)	39.2	117.0	0.53
Cyhalofop-butyl 90 g/ha (30 DAS)	89.2	143.9	1.37
Fenoxaprop 60 g/ha (30 DAS)	121.3	153.0	2.45
Cyhalofop-butyl + (chlorimuron + metsulfuron) 90 + 20 g/ha (30 DAS)	102.2	137.9	1.48
Fenoxaprop + (chlorimuron + metsulfuron) 60 + 20 g/ha (30 DAS)	156.0	149.3	3.00
Azimsulfuron (50 % WP) 35 g/ha (20 DAS)	163.4	149.4	2.08
Bispyribac- sodium 25 g/ha (20 DAS)	176.7	123.7	3.13
Fenoxaprop+ ethoxysulfuron g/ha (30 DAS)	161.5	157.5	3.48
Oxyflurofen + 2,4-D 300 + 500 g/ha (4 *fb* 30 DAS)	57.2	161.2	1.01
Two hand weedings of 20 and 40 DAS	169.0	164.3	3.50
Weedy	29.0	102.5	0.35
LSD (P=0.05)	21.0	65.9	0.37

DAS = Days after seeding

weed control efficiency was recorded with twice hand weeding at 20 and 40 DAS (89.9%) followed by fenoxaprop + ethoxysulfuron 60 + 15 g/ha, fenoxaprop + ready mix of chlorimuron + metsulfuron 60 + 20 g/ha, bispyribac-sodium 25 g/ha and fenoxaprop 60 g/ha. Ramchandiran and Balasubramanian (2012) also reported the higher weed control efficiency of fenoxaprop + ready mix of chlorimuron + metsulfuron in aerobic rice.

Effect on crop

All the weed control treatments produced significantly more number of panicles/m^2, grains per panicle and grain yield than weedy check (Table 3). The highest grain yield (3.50 t/ha) was recorded with hand weeding twice at 20 and 40 DAS which was statistically at par with fenoxaprop + ethoxysulfuron 60 + 15 g/ha (3.48 t/ha) and bispyribac-sodium 25 g/ ha (3.13 t/ha). Uncontrolled weeds in weedy check plots caused an average reduction in yield to the extent of 89.9% in 2010 and 88.8% 2011 when compared with fenoxaprop + ethoxysulfuron 60 + 15 g/ha and bispyribac-sodium 25 g/ha mainly due to highest weed density and biomass in weedy check plots. The lowest yield (352 kg/ha) was recorded in weedy check.

It was concluded that among the herbicidal treatments, combination of fenoxaprop + ethoxysulfuron 60 + 15 g/ha applied at 20 DAS and fenoxaprop + ready mix of chlorimuron + metsulfuron 60 + 20 g/ha at 30 DAS were found more effective in controlling weeds and attaining higher yield of direct dry-seeded rice.

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Integrated use of herbicides to enhance yield and economics of direct-seeded rice

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ABSTRACT

A field study was conducted at Dr. B.S. KKV, Dapoli (Maharashtra) farm in *Kharif* seasons (2012 to 2015) on rice to evaluate the effect of different herbicide and herbicide combination on yield attributes, yield and economics. Based on pooled analysis, significantly lower dry weight of grasses, sedges and broad-leaved weeds and higher yield attributes and yield were recorded in weed free check (HW at 20, 40, and 60 DAS) followed by pendimethalin as pre-emergence (PE) 1000 g/ha at 0 to 2 DAS *fb* manual weeding at 25-30 DAS and pendimethalin 1000 g/ha at 0 to 2 DAS (PE) *fb* bispyribac-Na 25 g/ha at 20 DAS (3 to 4 leaf stage) *fb* manual weeding (45 DAS). The highest weed control index (95.00%) was recorded by weed free check (HW at 20, 40, and 60 DAS) followed by pendimethalin 1000 g/ha at 0 to 2 DAS *fb* manual weeding at 25-30 DAS (92.84%) and pendimethalin 1000 g/ha at 0 to2 DAS *fb* bispyribac-Na 25 g/ha at 20 DAS *fb* manual weeding at 45 DAS (89.87%). The lowest weed index was recorded with the application of pendimethalin 1000 g/ha at 0 to 2 DAS *fb* manual weeding (25-30 DAS) and pendimethalin 1000 g/ha at 0 to 2 DAS *fb* bispyribac-Na 25 g/ha at 20 DAS (3 to 4 leaf stage) *fb* manual weeding at 45 DAS. The highest net returns with B-C ratio of 1.28 was obtained in the application of pendimethalin 1000 g/ha at 0 to 2 DAS (PE) *fb* manual weeding (25-30 DAS) followed by weed free check (HW at 20, 40 and 60 DAS).

Key words: Direct-seeded rice, Economics, Herbicides, Weed control, Yield attributes, Yield

In India, rice is cultivated under various ecosystems *viz.* transplanted and direct sown under irrigated and rainfed situations. Rice is generally established through transplanting method and this practice has been widely adopted by the farmers in Konkan region of Maharashtra. However, with increasing scarcity and cost of human labour, direct seeding of rice through drum seeder is one of the technological options which will not only address this problem but also increase the rice productivity. Direct sowing of rice offers the advantage of quicker, easier sowing, reduce labour requirement, hastens crop maturity and more economical. However, the weed infestation is the main problem in this method. Weed pressure is often two to three times more in direct-seeded rice as compared to transplanted one. The yield losses due to weeds are 36% in transplanted rice but as high as 84% in direct sown rice (Ravichandran 1991). The extent of yield reduction due to weed infestation was worked out at 15-20% under transplanted system and more than 50% in direct-seeded system (Pillai and Rao 1974). Infestation of heterogeneous weed flora becomes the biggest biological constraints in direct-seeded rice. The success of direct-seeded rice is dependent upon efficient weed control. For direct-seeded rice, it is important to keep field weed free for at least first 30 days. Therefore, use of pre-emergence or early post-emergence herbicides is effective and economical at initial stages. The pre-emergence or early post-emergence herbicide either prevents weed seeds to emerge or inhibits the growth of seedlings. Use of these herbicides along with post-emergence herbicides or cultural, mechanical and agronomic methods of weed control gives effective control of weeds. Thus, the present study was undertaken to explore the possibility of use of herbicides under such situations for efficient and economic weed management to increase the yield level in direct seeded rice.

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MATERIALS AND METHODS

A field experiment was conducted during 2012 to 2015 at Research Farm of Department of Agronomy, College of Agriculture, Dapoli (Maharashtra). The experimental site was located at west coast 250 meter height from mean sea level having annual average rainfall 3500 mm with 95 to 100 rainy days throughout *Kharif* season. The experiment was laid out in randomized block design with three replications. The ten treatment comprised; bispyribac-Na 25 g/ha at 20 DAS (3-4 leaf stage), pendimethalin as pre-emergence (PE) 1000 g/ha at 0 to 2 DAS *fb* bispyribac-Na 25 g/ha at 20 DAS (3-4 leaf stage), oxadiargyl 100 g/ha at 0 to 2 DAS *fb* bispyribac-Na 25 g/ha at 25 DAS, pyrazosulfuron 20 g/ha at 0 to 3 DAS *fb* bispyribac-Na 25 g/ha at 25 DAS, pendimethalin 1000 g/ha at 0 to 3 DAS *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS, pendimethalin 1000 g/ha at 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS, bispyribac-Na 20 g/ha + chlorimuron + metsulfuron at 4 g/ha 20 DAS, three mechanical weeding (cono/rotary weeder) at 20, 40 and 60 DAS, weed free check (HW at 20,40, and 60 DAS) and weedy check. The soil of the experimental plot was sandy clay loam in texture, acidic in pH and medium in organic carbon content. It was low in available nitrogen (282 kg/ha), medium in available phosphorus (10.8 kg/ha) and high in available potassium (236 kg/ha).

The gross plot size was 5.0 x 3.0 m. The seed of rice variety *'Ratnagiri-1'* was treated with thiram at the rate of 3 g/kg of seed used for sowing. Sowing was done by opening small furrows of about 3 cm depth with the help of marker at a distance of 20 cm between the lines. The rice seed was sown about 3 cm deep manually at the rate of 60 kg/ha and covered with the soil. The recommended dose of fertilizer (100:50:50 NPK kg/ha) was applied to all the plots. Half dose of nitrogen and full dose of phosphorus and potassium was applied at the time of sowing while remaining half dose of nitrogen was applied at 30 days after sowing of crop. The uniform representative samples of crop as well as weeds were randomly collected from each plot. Data were analyzed (pooled analysis) statistically by using standard methods of Panse and Sukhatme (1984).

RESULTS AND DISCUSSION

Effect on weed growth

Various weed control measures significantly influenced growth of monocots during all the years of experimentation and in pooled results (Table 1 and 2). During the first year (2012) of the experiment, use of pendimethalin *fb* manual weeding significantly reduced the growth of monocots as compared to use of bispyribac-Na, pendimethalin *fb* bispyribac-Na, pyrazosulfuron *fb* bispyribac–Na, weedy check and remained at par with rest of the treatments. However, during other years and in pooled results, the use of pendimethalin *fb* manual weeding recorded significantly lower weed growth than rest of the treatments except pendimethalin *fb* bispyribac-Na *fb* manual weeding and weed free check. Various weed control measures tried did not significantly influence growth of broad-leaved weeds (BLWS) during individual years as well as in pooled results at 60 DAS. Walia *et al.* (2012) also reported similar results in drilled rice.

Application of pendimethalin *fb* bispyribac–Na *fb* manual weeding, pendimethalin *fb* manual weeding and weed free check remained at par with each other and reduced significantly the weed growth of monocots during 1st, 3rd and 4th years as well as in pooled results at 90 DAS. However, weed free check (3 HW) reduced the weed growth of monocots significantly during 2013 over all other weed control measures tried except use of pendimethalin *fb* manual weeding.

Weed growth of BLWS was reduced significantly due to various weed control measures tried over weedy check and remained at par with each other during the year 2012, 2013, 2015 and in pooled results. However, weed free check (3 HW) reduced significantly the growth of BLWS during the year 2014 over all other treatments except the use of pendimethalin *fb* bispyribac-Na *fb* manual weeding and pyrazosulfuron *fb* bispyribac-Na.

The pooled data indicated that, the highest weed control index was recorded under weed free check (84.76 and 95.00 at 60 and 90 DAS) followed by pendimethalin *fb* manual weeding and pendimethalin *fb* bispyribac-Na *fb* manual weeding at all the stages of observations. These results were in conformity with the findings of Walia *et al.* (2012) and Ganie *et al.* (2013).

Effect on yield attributes and yield

Different weed control treatments significantly influenced the yield attributes, *viz*. plant height, number of tillers and weight of filled grains per panicle over weedy check (Table 1). Weed free check (three hand weeding) recorded significantly higher plant height over all other treatments followed by pendimethalin 1000 g/ha at 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS while in respect of number of tillers, weed free check (HW at 20, 40, and 60 DAS) recorded significantly higher number of tillers except pendimethalin 1000 g/ha at 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS. Weed free check (HW at 20,40, and 60 DAS) also recorded significantly higher weight of filled grains per panicle as compared to bispyribac-Na at 25 g/ha at 20 DAS, oxadiargyl at 100 g/ha 0 to 2 DAS *fb* bispyribac-Na at 25 g/ha 25 DAS, pendimethalin at 1000 g/ha 0 to 3 DAS *fb* bispyribac-Na at 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS and weedy check. Similar results of higher yield attributes of direct-seeded rice were reported by Veeraputhiran and Balasubramanian

Table 1. Effects of herbicide combinations on weed growth at 60 DAS (no. 0.25 m^2) (four year pooled mean)

Treatment	Grasses and sedges					Broad-leaved weeds					WCI (%)				
	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled
Bispyribac-Na 25 g/ha at 20 DAS	24.67 (4.74)	3.84 (1.97)	14.67 (3.88)	6.31 (2.58)	12.37 (3.55)	00.00 (0.71)	00.00 (0.71)	12.50 (3.59)	0.25 (0.85)	3.19 (1.91)	30.2	65.7	12.8	59.2	33.7
Pendimethalin (PE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	19.67 (4.34)	2.75 (1.79)	12.33 (3.56)	6.67 (2.67)	10.35 (3.28)	0.33 (0.88)	0.27 (0.87)	6.33 (2.61)	1.51 (1.41)	2.11 (1.61)	43.4	73.0	40.1	49.2	46.9
Oxadiargyl (PE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	15.00 (3.40)	3.53 (2.00)	14.00 (3.80)	8.45 (2.99)	10.25 (3.24)	0.33 (0.88)	0.00 (0.71)	5.17 (2.37)	0.98 (1.16)	1.62 (1.45)	56.6	68.5	38.5	41.4	49.4
Pyrazosulfuron (PE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	27.33 (4.83)	4.09 (2.13)	10.00 (3.30)	8.61 (2.98)	14.51 (3.83)	0.00 (0.71)	0.00 (0.71)	3.23 (1.92)	2.37 (1.69)	1.40 (1.38)	22.7	63.5	57.6	29.9	32.2
Pendimethalin (PE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	10.67 (2.79)	0.44 (0.96)	5.00 (2.34)	3.39 (1.96)	4.87 (2.24)	0.33 (0.88)	0.09 (0.77)	2.33 (1.66)	0.95 (1.15)	0.93 (1.19)	68.9	95.3	76.5	73.0	75.3
Pendimethalin (PE) 1000 g/ha *fb* manual weeding 25-30 DAS	1.00 (1.22)	0.12 (0.78)	6.50 (2.64)	1.60 (1.42)	2.31 (1.67)	0.33 (0.88)	0.36 (0.91)	4.17 (2.14)	0.00 (0.71)	1.22 (1.30)	96.2	95.7	65.8	90.1	83.9
Bispyribac-Na 20 g/ha + Almix 4 g/ha at 20 DAS (chlorimuron + metsulfuron)	10.33 (3.18)	2.42 (1.57)	13.83 (3.78)	6.23 (2.55)	8.20 (2.94)	3.33 (1.53)	0.00 (0.71)	7.00 (2.73)	1.31 (1.31)	2.91 (1.83)	61.3	78.4	33.2	53.2	52.6
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	4.33 (2.09)	4.37 (2.00)	12.67 (3.61)	4.13 (2.14)	6.38 (2.59)	1.33 (1.34)	0.44 (0.96)	4.17 (2.13)	0.87 (1.17)	1.70 (1.48)	84.0	57.0	46.0	68.9	65.6
Weed free check (HW at 20,40, and 60 DAS)	2.00 (1.52)	0.42 (1.03)	6.83 (2.70)	3.30 (1.94)	3.14 (1.91)	0.33 (0.88)	0.00 (0.71)	2.12 (2.26)	0.23 (0.83)	0.67 (1.08)	93.4	96.2	71.3	78.1	84.8
Weedy check	32.67 (5.70)	10.80 (3.25)	17.50 (4.22)	12.69 (3.63)	18.42 (4.34)	2.67 (1.45)	0.40 (0.98)	13.67 (6.87)	3.41 (1.92)	5.04 (2.35)	-	-	-	-	-
LSD (P=0.05)	- (2.39)	- (1.05)	- (0.45)	- 0.70	- (0.85)	- (N.S.)	- (N.S.)	- (N.S)	- (N.S.)	- (N.S.)					

Figures in parentheses indicate square root transformations $\sqrt{x + 0.5}$; PE= Pre-emergence

Table 2. Effects of herbicide combinations on weed growth at 90 DAS (no. 0.25/m^2) (four year pooled mean)

Treatment	Grasses and Sedges					Broad-leaved weeds					WCI (%)				
	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled
Bispyribac-Na 25 g/ha at 20 DAS	33.50 (5.76)	102.00 (9.87)	25.38 (5.08)	2.67 (1.77)	39.48 (6.32)	00.00 (0.71)	00.00 (0.71)	18.70 (4.36)	2.27 (1.66)	1.66 (1.47)	68.5	16.4	24.3	56.8	32.1
Pendimethalin (PE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	20.00 (4.30)	23.67 (4.00)	18.04 (4.29)	2.87 (1.83)	12.71 (3.53)	1.33 (1.39)	1.00 (1.17)	9.10 (3.06)	2.65 (1.77)	2.26 (1.65)	81.1	79.8	53.4	51.7	75.3
Oxadiargyl (PE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	36.83 (6.02)	86.33 (8.27)	20.37 (4.56)	2.82 (1.81)	32.64 (5.45)	1.17 (1.22)	0.33 (0.88)	9.47 (3.14)	2.11 (1.61)	1.69 (1.48)	66.3	29.0	48.7	56.9	43.4
Pyrazosulfuron (PE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	28.83 (5.13)	66.33 (7.98)	29.78 (5.50)	3.16 (1.91)	25.96 (5.04)	0.00 (0.71)	0.33 (0.71)	6.18 (2.56)	2.68 (1.78)	1.40 (1.37)	74.4	45.4	38.2	48.9	54.9
Pendimethalin (PE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	1.00 (1.15)	12.33 (3.22)	10.81 (3.35)	1.08 (1.25)	4.44 (2.18)	1.67 (1.45)	1.00 (1.22)	3.70 (2.04)	2.08 (1.58)	1.70 (1.48)	97.6	89.1	75.1	72.4	89.9
Pendimethalin (PE) 1000 g/ha *fb* manual weeding 25-30 DAS	2.50 (1.53)	1.33 (1.27)	12.90 (3.65)	2.18 (1.64)	2.41 (1.69)	1.50 (1.38)	1.33 (1.34)	6.19 (2.90)	1.99 (1.55)	1.93 (1.56)	96.4	97.8	67.2	63.5	92.8
Bispyribac-Na 20 g/ha + Almix 4 g/ha at 20 DAS (chlorimuron + metsulfuron)	17.50 (4.16)	112.67 (10.43)	21.61 (4.68)	2.67 (2.67)	34.34 (5.84)	0.00 (0.71)	0.33 (0.88)	13.16 (3.64)	2.77 (1.81)	1.69 (1.48)	84.5	7.4	40.3	52.4	40.5
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	10.50 (3.24)	53.00 (6.51)	18.26 (4.31)	2.60 (1.76)	17.60 (4.11)	15.17 (3.36)	0.67 (1.05)	7.20 (2.75)	1.99 (1.54)	5.14 (2.28)	77.2	56.0	56.3	59.9	62.5
Weed free check (HW at 20, 40 and 60 DAS)	1.67 (1.26)	1.00 (1.22)	11.32 (3.43)	2.31 (1.67)	2.10 (1.60)	0.17 (0.81)	0.33 (0.88)	3.48 (1.97)	1.24 (1.30)	0.93 (1.19)	98.4	98.9	74.6	69.0	95.0
Weedy check	74.50 (8.47)	116.67 (10.78)	32.90 (5.77)	5.59 (2.45)	46.96 (6.79)	38.33 (5.28)	5.33 (2.12)	25.32 (5.07)	5.85 (2.51)	13.65 (3.54)	-	-	-	-	-
LSD (P=0.5)	- (1.61.)	- (1.52)	- (0.45)	- (0.42)	- (1.31)	- (3.42)	- (1.19)	- 0.70)	- (0.52)	- (1.25)					

Figures in parentheses indicate square root transformations $\sqrt{x + 0.5}$; PE= Pre-emergence

(2013) and Chauhan *et al*. (2013). Consequently, weed free check (Table 4) (HW at 20, 40, and 60 DAS) produced significantly higher grain and straw yield (3.88 and 4.68 t/ha), respectively over rest of the treatments except pendimethalin 1000 g/ha 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS (3.68 and 4.38 t/ha) and pendimethalin 1000 g/ha at 0 to 3 DAS *fb* bispyribac-Na at 25 g/ha 25 DAS *fb* manual weeding at 45 DAS (3.58 and 4.40 t/ha), which were at par with each other (Table 2). Weed free check (HW at 20, 40, and 60 DAS) also indicated higher per cent increment of grain yield (162.8%) over weedy check followed by pendimethalin 1000 g/ha 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS (148.9%). Compared to best treatment of weed free check (HW at 20, 40, and 60 DAS), weed index (WI) which indicate the increase in grain yield was maximum under pendimethalin 1000 g/ha 0 to 2 DAS *fb* manual

Table 3. Effects of herbicide combinations on growth and yield attributes of rice (four year pooled mean)

Treatment	Height (cm)					No. of tillers					Panicle length (cm)					Weight of filled Grain /panicles				
	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled
Bispyribac-Na 25 g/ha at 20 DAS	52.4	65.7	83.3	69.9	67.8	37.3	96.0	62.0	40.3	58.9	18.4	19.3	19.3	18.8	18.9	1.03	2.97	1.98	2.07	2.07
Pendimethalin (PE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	57.0	71.5	89.7	75.0	73.3	31.0	64.0	61.7	44.3	46.6	18.1	21.5	20.2	19.4	19.8	1.47	3.70	2.52	2.19	2.19
Oxadiargyl (PE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	59.7	63.5	88.2	74.7	71.5	50.0	72.7	64.0	43.3	57.5	19.7	20.3	20.3	19.7	20.0	2.01	4.18	2.40	2.06	2.06
Pyrazosulfuron (PE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	51.4	66.9	86.8	73.9	69.8	47.0	56.0	63.0	44.7	52.7	18.5	19.3	18.4	18.9	18.8	2.11	2.64	2.00	2.23	2.23
Pendimethalin (PE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	63.7	72.6	91.3	79.3	76.6	48.3	62.7	66.0	51.3	54.2	19.3	19.6	31.4	19.9	20.0	2.01	3.38	3.19	2.08	2.08
Pendimethalin (PE) 1000 g/ha *fb* manual weeding 25-30 DAS	59.7	69.7	93.2	78.9	75.4	60.7	75.3	69.0	50.0	63.7	19.9	20.5	21.5	20.1	20.5	2.25	3.35	3.08	2.24	2.24
Bispyribac-Na 20 g/ha + Almix 4 g/ha at 20 DAS (chlorimuron + metsulfuron)	49.5	76.1	83.3	72.2	70.3	35.3	60.0	60.7	46.3	50.6	18.9	21.4	19.0	18.9	19.6	2.09	3.17	2.48	2.26	2.26
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	55.7	71.5	89.5	74.4	73.0	36.7	76.0	62.0	47.0	53.6	18.2	20.7	20.4	19.4	19.7	1.52	3.52	2.48	2.21	2.21
Weed free check (HW at 20,40 and 60 DAS)	60.8	76.4	91.0	80.6	77.7	51.7	80.0	68.0	56.3	64.0	19.3	20.4	20.7	20.0	20.1	2.22	3.68	2.63	2.27	2.27
Weedy check	54.6	61.2	79.3	62.9	64.5	32.0	66.0	56.0	45.7	45.3	19.5	18.7	16.8	17.7	18.5	2.04	2.23	1.88	1.86	1.86
LSD (P=0.05)	N.S.	N.S	1.0	1.7	0.8	N.S.	N.S	0.8	0.6	2.6	N.S.	N.S	0.3	N.S.	N.S.	N.S.	0.88	0.45	0.08	0.08

Table 4. Effects of herbicide combinations on yield and yield attributes of rice (four year pooled mean)

Treatment	Grain yield t/ha					Straw yield t/ha					WI (%)				
	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled	2012	2013	2014	2015	Pooled
Bispyribac-Na 25 g/ha at 20 DAS	1.95	2.31	2.86	2.78	2.23	2.04	2.42	4.91	3.35	2.93	33.64	56.06	27.72	17.09	42.59
Pendimethalin (PE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	1.79	5.04	3.52	2.78	3.04	2.00	5.30	5.47	3.39	3.79	38.95	4.18	11.23	16.94	21.77
Oxadiargyl (PE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	1.80	4.06	3.68	2.89	3.10	1.91	4.30	5.29	3.54	3.76	38.91	22.95	7.27	13.72	19.99
Pyrazosulfuron (PE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	1.64	3.28	2.92	2.58	2.61	1.91	3.68	4.19	3.06	3.21	44.15	37.65	26.24	23.05	32.83
Pendimethalin (PE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	2.57	4.67	3.92	3.20	3.58	2.89	5.01	5.82	3.86	4.40	12.55	11.89	1.14	4.41	7.70
Pendimethalin (PE) 1000 g/ha *fb* manual weeding 25-30 DAS	2.32	5.23	3.94	3.21	3.68	2.41	5.65	5.55	3.88	4.38	21.02	0.59	0.48	4.29	5.26
Bispyribac-Na 20 g/ha + Almix 4 g/ha at 20 DAS (chlorimuron + metsulfuron)	1.13	3.83	2.77	2.73	2.62	1.22	4.14	4.67	3.32	3.34	61.53	27.22	30.05	18.49	32.57
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	1.79	3.75	3.56	2.51	2.90	1.91	4.05	5.29	3.13	3.59	39.15	28.74	10.24	25.23	25.25
Weed free check (HW at 20,40 and 60 DAS)	2.94	5.26	3.96	3.35	3.88	3.04	5.68	5.96	4.02	4.68	-	-	-	-	-
Weedy check	0.33	1.09	2.00	2.49	1.48	0.38	1.18	3.43	2.92	1.98	88.67	79.31	49.65	25.77	61.94
LSD (P=0.05)	0.16	0.21	0.07	0.16	0.08	0.11	0.12	0.15	0.17	0.10	-	-	-	-	-

Table 5. Pooled yield and economics for weed control measures applied in rice

Treatment	Pooled yield (2012 to 2015)		Economics			
	Grain yield (t/ha)	Straw yield (t/ha)	Gross Expenditure (x10^3 `/ha)	Gross returns (x10^3 `/ha)	Net returns (x10^3 `/ha)	B-C ratio
Bispyribac-Na 25 g/ha at 20 DAS	2.23	2.93	43.41	39.29	-4.12	0.91
Pendimethalin (PE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	3.04	3.79	52.55	53.12	0.57	1.01
Oxadiargyl (PE) 100 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	3.10	3.76	52.74	54.09	1.35	1.03
Pyrazosulfuron (PE) 20 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS	2.61	3.21	44.69	45.52	0.83	1.02
Pendimethalin (PE) 1000 g/ha *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS	3.58	4.40	52.50	62.52	10.02	1.19
Pendimethalin (PE) 1000 g/ha *fb* manual weeding 25-30 DAS	3.68	4.38	50.03	63.92	13.89	1.28
Bispyribac-Na 20 g/ha + Almix 4 g/ha at 20 DAS (chlorimuron + metsulfuron)	2.62	3.34	44.33	45.93	1.60	1.04
Three mechanical weeding 20, 40 and 60 DAS (cono / rotary weeder)	2.90	3.59	55.22	50.70	-4.52	0.92
Weed free check (HW at 20,40 and 60 DAS)	3.88	4.68	56.87	67.57	10.70	1.19
Weedy check	1.48	1.98	35.93	26.11	-9.82	0.73

* selling rate 1) Rice – 1500/- per Quintal (q) 2) Straw – 200/- per q., * Herbicide rate: 1) Bispyribac-Na – 7950/liter, 2) Pendimethalin – 500/liter, 3) Oxadiargyl – 6772/kg, 4) Pyrazosulfuron – 4000/kg, 5) chlorimuron + metsulfuron – 21750/kg; PE= Pre-emergence

weeding at 25 to 30 DAS (5.26%) closely followed by pendimethalin at 1000 g/ha 0 to 3 DAS *fb* bispyribac-Na 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS (7.70%). Similar results of higher yield attributes of direct-seeded rice were reported by Veeraputhiran and Balasubramanian (2013) and Naseeruddin and Subramanyam (2013).

Economics

The highest net returns of ` 13,887/ ha was obtained with the application of pendimethalin 1000 g/ha at 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS followed by weed free check (HW at 20, 40 and 60 DAS) (` 10,698/ ha) with B-C ratio of 1.28 and 1.19, respectively (Table 5).

On the basis of four years pooled data, it was concluded that application of pendimethalin 1000 g/ ha at 0 to 2 DAS *fb* manual weeding at 25 to 30 DAS was most effective and economical treatment (BC ratio 1.28) followed by weed free check (HW at 20, 40, and 60 DAS) (BC ratio 1.19) to control weeds effectively in direct-seeded drilled rice during *Kharif* season.

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Weed flora of raised bunds and undulated lands growing along the rice fields of Kashmir Valley

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ABSTRACT

For an effective weed management in the rice fields, it is crucial to identify the actual weeds as well as those growing on the raised bunds and undulated lands nearby rice fields. The present study was carried out with this aim to record the weeds growing on bunds and nearby undulated lands of the rice fields in Kashmir Valley, so that not only the actual weeds inside the rice field but also the nearby growing weed species that may pose future risk could also be targeted under the weed management practices. During the present study, 58 weed species belonging to 45 genera and 27 families were recorded along raised bunds and undulated lands of rice fields in Kashmir Valley. Of these, 38 weed species were terrestrial and 20 were semi-aquatic species; and it is the latter set of species that can become the future weeds of rice fields in the region.

Key words: Bund weeds, Management, Semi-aquatic, Terrestrial, Weed flora

Rice (*Oryza sativa*) is one of the top most cereal crops providing food for more than half of world's human population (Kumar *et al.* 2008, Mulungu *et al.* 2011). Being staple food for more than 3 billion people across the world, rice provides 50-80 per cent daily calorie intake (Choudhary *et al.* 2011). Throughout the world, India is the second largest producer of rice after China; and rice is the second most important crop in India (Savary *et al.* 2005). The crop plays a pivotal role in the economy of India and thus occupies top priority in the agricultural policy and food security of the country (Dangwal *et al.* 2011).

Uncontrolled infestation by obnoxious weeds is a serious problem for rice cultivation, and there are estimates that weeds incur an annual rice yield loss of 15-21% worldwide (Oerke *et al.* 1994). In fact, out of total losses incurred to rice due to various biotic stressors, weeds are known to account for one-third (Rao and Nagamani 2007). It has been estimated that infestation of weeds in rice fields reduces the grain yield by 75.8, 70.6 and 62.6% in dry seeded rice, wet seeded rice and transplanted rice, respectively (Singh *et al.* 2005).

In the Kashmir Valley, rice is regarded to be more than just the staple food, and it finds its way in local parlance for the word: "meal" (Ganie *et al.* 2015). A relatively small area of about 0.27 million hectares of land are under rice cultivation in the region and the crop contributes significantly to the regional economy (Ganie *et al.* 2015). Although the rice is crucially linked to the livelihood of local inhabitants in the Kashmir Valley, yet the yield loss incurred due to infestation of various weeds is one of the major problems in the region. It is in this backdrop the present study was undertaken to identify and document the weed species growing along raised bunds and on undulated lands of rice fields across the Kashmir Valley with an emphasis on taxonomic diversity, habit, occurrence and life span, which in turn, can provide useful insights in the development of effective weed management practices.

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MATERIALS AND METHODS

Field surveys were conducted across the Kashmir Valley to identify weeds growing along raised bunds and in between undulated lands of rice fields during 2010-2014, in the months of April to October. Being situated in northern fringe of the Indian sub-continent, the Valley lies between 33°22' and 34°50' N latitudes and 73°55'and 73°33' E longitudes covering an area of about 16,000 sq. km. During the present study, 3 sites from each district with 10 spots at each site of Kashmir Valley have been selected to record the weed flora. Field surveys were conducted twice a month in each site for collection of weed species specimens. The collected plant specimens were pressed, dried, preserved and properly identified with the help of available literature

(Hooker 1894, Stewart 1972, Cook 1995). The properly processed herbarium specimens were deposited at Kashmir University Herbarium (KASH) for future voucher specimens.

RESULTS AND DISCUSSION

Fifty eight weed species growing along raised bunds and in between undulated lands of rice fields across the Kashmir Valley were recorded (Table 1). These species belong to 45 genera in 27 families; of the latter, 23 belong to dicotyledons and 4 to monocotyledons. Habit-wise, study showed that 20 species were aquatic/semi-aquatic and 38 were terrestrial. Based on the occurrence, most of the weed species grew on both the raised bunds and undulated lands. Although rice is an annual crop, however majority of the weeds recorded were perennials (37 species), followed by 19 annual and 2 biennial species. In addition to 40 weed species previously reported by Ganie *et al*. (2015) as the actual weed species that grow inside beds in the rice fields of Kashmir Valley, one more species namely *Butomus umbellatus* L. has also been recently recorded as weed of rice fields at various places in the Valley. Based on this observation, it was predicted that among the 20 aquatic/semi-aquatic species recorded during the present study which currently are still growing along margins of rice fields can become potential future weed species of the rice crop in the region.

From weed management point of view, correct taxonomic identification and the identification of potential habitats that serve as pathway for the weed species assumes first and foremost priority. Therefore, the present study recommends that, in addition to the actual weeds of the rice crop which are primary target, the weed management practices should also focus on potential weed species that inhabit side-by habitats in rice fields, such as raised bunds, undulated lands *etc*, which may pose risk in future. Such an informed early prediction protocol for future weed species need to be integrated in the overall weed management, because the chances of weed control are maximal at this stage of infestation.

Table 1. Weed species growing on raised bunds/or in between undulated lands of rice fields in Kashmir Valley

Plant species	Family	Habit	Occurrence	Life span
Achillea millefolium L.	Asteraceae	Terrestrial	RB and UL	Perennial
Cichorium intybus L.	Asteraceae	Terrestrial	RB and UL	Perennial
Conyza canadensis (L.) Cronq.	Asteraceae	Terrestrial	RB and UL	Annual
Galinsoga parviflora Cav.	Asteraceae	Terrestrial	RB and UL	Annual
Senecio chrysanthemoides DC.	Asteraceae	Terrestrial	RB and UL	Perennial
Sonchus arvensis L.	Asteraceae	Terrestrial	RB and UL	Perennial
Sonchus oleraceus L.	Asteraceae	Terrestrial	RB and UL	Biennial
Tagetes erecta L.	Asteraceae	Terrestrial	RB and UL	Annual
Tagetes minuta L.	Asteraceae	Terrestrial	RB and UL	Annual
Tagetes patula L.	Asteraceae	Terrestrial	RB and UL	Annual
Xanthium strumarium L.	Asteraceae	Terrestrial	RB and UL	Annual
Myosotis caespitosa Schultz	Boraginaceae	Terrestrial	RB and UL	Perennial
Capsella bursa-pastoris (L.) Medic.	Brassicaceae	Terrestrial	RB and UL	Annual
Rorippa indica (L.) Hiern	Brassicaceae	Semi-aquatic	UL	Annual
Nasturtium officinale L.	Brassicaceae	Aquatic	UL	Perennial
Thlaspi arvense L.	Brassicaceae	Terrestrial	RB and UL	Annual
Cannabis sativa L.	Cannabaceae	Terrestrial	RB and UL	Annual
Chenopodium album L.	Chenopodiaceae	Terrestrial	RB and UL	Annual
Convolvulus arvensis L.	Convolvulaceae	Terrestrial	RB and UL	Perennial
Euphorbia prostrata Ait.	Euphorbiaceae	Terrestrial	RB and UL	Annual
Lathyrus aphaca L.	Fabaceae	Terrestrial	RB and UL	Annual
Trifolium pratense L.	Fabaceae	Terrestrial	RB and UL	Perennial
Trifolium repens L.	Fabaceae	Terrestrial	RB and UL	Perennial
Vicia sativa L.	Fabaceae	Terrestrial	RB and UL	Annual
Medicago lupulina L.	Fabaceae	Terrestrial	RB and UL	Perennial
Geranium nepalense Sweet	Geraniaceae	Terrestrial	RB and UL	Perennial
Myriophyllum spicatum L.	Haloragaceae	Aquatic	UL	Perennial
Ocimum basilicum L.	Lamiaceae	Terrestrial	RB and UL	Perennial
Prunella vulgaris L.	Lamiaceae	Terrestrial	RB and UL	Perennial
Scutellaria discolor Colebr.	Lamiaceae	Terrestrial	RB and UL	Perennial
Scutellaria galericulata L.	Lamiaceae	Semi-aquatic	RB and UL	Perennial
Lythrum salicaria L.	Lythraceae	Aquatic	UL	Perennial

Plant species	Family	Habit	Occurrence	Life span
Nelumbo nucifera Gaertn.	Nelumbonaceae	Aquatic	UL	Perennial
Epilobium hirsutum L.	Onagraceae	Semi-aquatic	UL	Perennial
Oenothera drummondii Hook. F	Onagraceae	Semi-aquatic	UL	Perennial
Spiranthes sinensis (Pers.) Ames	Orchidaceae	Semi-aquatic	UL	Perennial
Oxalis corniculata L.	Oxalidaceae	Terrestrial	RB and UL	Perennial
Plantago lanceolata L.	Plantaginaceae	Terrestrial	RB and UL	Perennial
Plantago major L.	Plantaginaceae	Terrestrial	RB and UL	Perennial
Cynodon dactylon (L.) Pers.	Poaceae	Terrestrial	RB and UL	Perennial
Poa angustifolia L.	Poaceae	Terrestrial	RB and UL	Perennial
Poa annua L.	Poaceae	Terrestrial	RB and UL	Annual
Poa pratensis L.	Poaceae	Terrestrial	RB and UL	Perennial
Persicaria amphibium (L.) Delarbe	Polygonaceae	Aquatic	UL	Perennial
Persicaria nepalensis (Meisn) Miyabe	Polygonaceae	Aquatic	UL	Annual
Persicaria lapathifolium (L.) Delarbe	Polygonaceae	Semi-aquatic	UL	Annual
Rumex dentatus L.	Polygonaceae	Semi-aquatic	UL	Perennial
Rumex nepalensis Spreng	Polygonaceae	Semi-aquatic	UL	Perennial
Portulaca oleracea L.	Portulacaceae	Terrestrial	UL	
Stuckenia pectinata (L.) Börner	Potamogetonaceae	Aquatic	UL	Perennial
Potamogeton crispus L.	Potamogetonaceae	Aquatic	UL	Biennial
Ranunculus sceleratus L.	Ranunculaceae	Semi-aquatic	UL	Perennial
Rubia cordifolia L.	Rubiaceae	Terrestrial	RB and UL	Perennial
Veronica anagallis-aquatica L.	Scrophulariaceae	Semi-aquatic	UL	Perennial
Veronica beccabunga L.	Scrophulariaceae	Semi-aquatic	UL	Perennial
Solanum americanum Mill.	Solanaceae	Terrestrial	RB and UL	Annual
Typha angustifolia L.	Typhaceae	Aquatic	UL	Perennial
Tribulus terrestris L.	Zygophyllaceae	Terrestrial	RB and UL	Annual

RB= Raised Bunds; UL= Undulated Land

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Irrigation schedule and crop geometry effect on weed management in maize + green gram intercropping system

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ABSTRACT

A field experiment was conducted under West Central Table Land Zone, Odisha during winter (*Rabi*) seasons of 2013-14 and 2014-15 to study the effect of irrigation schedule and planting geometry on weed control and productivity in maize + green gram intercropping. The results revealed that irrigating the crop at 0.8 IW/CPE recorded lowest weed density (23.6/ m^2) and weed dry matter (10.9 g/ m^2). This moisture regime also produced highest yield of individual component (3.36 t/ha for maize and 0.22 t/ha for greengram) of the system and the highest maize equivalent yield (4.4 t/ha). Intercropping of maize with green gram irrespective of their row ratio effectively reduced the weed density and dry weight at 60 days after sowing compared to pure cropping of maize. The grain yield of maize in all the intercropping system except 1:2 row ratio was statistically at par with its yield in pure stand. However the productivity of green gram significantly reduced in intercropping system compared to its sole cropping (0.35 t/ha). Maize equivalent yield in 2:2 planting pattern was remarkably high (4.87 t/ha) compared to other planting geometries tested. The highest B:C ratio was recorded at 0.80 IW/CPE (2.25) and with 2:2 planting pattern of maize + green gram (2.28).

Key words: Crop geometry, Irrigation schedule, Intercropping, Maize + green gram, Weed control

The cereal + legume intercropping system are one of the important agronomic practices, wherein the system yield is higher than respective sole crop yield. The canopy structure and root system of cereal crop is generally different from legume crops (Willey 1990). Maize is gaining importance as a commercial crop apart from food grain crop. Due to its initial slow growth, the inter row space of maize remains unused and becomes vulnerable to weed growth. Therefore, by introducing legume as intercrop in maize, the productivity of the system can be increased substantially reducing weed growth due to smothering effect of the inter crop.

Weed management in intercropping system needs more scientific effort to provide weed free situation for growth and development of main and inter crops. According to some researchers, weeds are prone to more competition under intercropping situation due to more competitive plant cover and high plant density. Intercropping provides a great scope for weed control because of more diverse utilization of available resources than in sole cropping. Short duration legumes such as green gram, black gram *etc.* can be grown in the wide inter row space of maize, which not only act as smother crop, but also give additional income. Weed control approach involving maize based intercropping system is very important to provide effective and acceptable weed control for realizing high production (Shah *et al.* 2011). Intercropping also reduces the cost of weeding and entails higher productivity of the system and better monetary return (Pandey and Prakash 2002). The intercropping system alone is not sufficient to achieve desired weed control as different intercrop provides different canopy coverage. The microclimate, which is mainly modified by the planting geometry in combination with irrigation management practices, may bring down weed infestation to a great extent. Hence, an attempt was made to control weeds through planting geometry and irrigation scheduling in an intercropping system.

MATERIALS AND METHODS

A field study was conducted under West Central Table Land agro-climatic Zone under AICRP on irrigation water management at Regional Research and Technology Transfer Station, Chiplima, Sambalpur, Odisha during the winter (*Rabi*) seasons of 2013-14 and 2014-15. The soil of experimental field was sandy clay loam, acidic (pH 5.65), low in organic carbon content (0.47%) and available N, P

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and K content was 242, 9.2 and 155 kg/ha, respectively. The experiment was laid out in split plot design consisting of four irrigation treatments in main plot, *viz*. irrigation at IW/CPE ratio of 0.7, 0.8, 0.9 and 1.0 and six planting geometry in sub plot, *viz*. sole maize (60 x 30 cm), sole green gram (30 x 10 cm), maize (100%) + green gram (50%) at 1:1 ratio, maize (66%) + green gram (66%) at 1:2 ratio, maize (100%) + green gram (33%) at 2:1 ratio and maize (100%) + green gram (50%) at 2:2 ratio. The sole crop of maize was planted at 60 x 30 cm spacing where as in paired row planting the spacing between the maize plants was reduced to 30 cm providing a gap of 90 cm between two paired rows. The green gram seeds were placed at a spacing of 30 x 10 cm. The seed rate and fertilizer dose were calculated as per percentage of plant population. In fertilizer calculation, nitrogen requirement for maize was only applied along with total phosphorus and potassium requirement for both the crops. The fertilizer N and K were given in 3 splits whereas all the P was given at the time of sowing. The herbicide oxyfluorfen 60 g/ ha was applied as pre-emergence to all the plots at 2 days after sowing. Weed smothering efficiency (WSE) is the capacity of intercrop to suppress the weeds as compared to sole crop. It was calculated with the following formula and expressed in percentage.

$$WSE = \frac{DMS - DMI}{DMS} \times 100$$

Where, DMS: Dry matter of weeds of sole crop, DMI: Dry matter of weeds of intercrop and WSE: Weed smothering efficiency.

RESULTS AND DISCUSSION

Effect on weed dynamics

The major weed flora observed in the field was grassy weeds like *Echinochloa crusgalli* (L.) Beauv, *Echinochloa colona* (L.) Linn, *Cynodon dactylon* (L.) Pers., *Digitaria sanguinalis* (L.) Scop, Sedges like *Cyperus rotundus* L. *Cyperus iria* L., broad – leaf weeds like *Commelina benghalensis* L., *Trianthema portulacastrum* L. *Convolvulus arvensis* L., *Amaranthus viridis L.*, *Phylanthus niruri* L. and *Portulaca oleracea* L.

Among various irrigation schedules 0.8 IW/ CPE gave the least weed count 23.6/m^2 and weed dry weight of 10.9 g/ m^2 followed by 0.90 IW/CPE with weed count of 27.9/m^2 and dry weight of 12.6 g/ m^2 and it was at par with 1.0 IW/CPE with respect to weed dry weight. Both the parameters increased with either increase or decrease in IW/CPE ratio. This might be due to better growth of plant at optimum moisture regime, which was negatively affected by increase or decrease in number of irrigations. Availability of less space for growth of weeds due to quick coverage of ground and more shading effect was also reported by Deshveer and Singh (2002). Weed smothering efficiency was highest at 0.8 IW/ CPE (34.16%) and it decreased with increase in soil moisture content (Table 1).

In the sub plots, different planting geometry of maize + green gram and sole green gram crop proved significantly superior to sole maize in reducing weed density and weed dry matter at 60 DAS (days after sowing). Paired row planting of maize and green gram in 2:2 ratio recorded the lowest weed density of

Table 1. Effect of moisture regime and intercropping on weed smothering efficiency and yield of maize and green gram (mean of two years)

Treatment	Weed population at harvest (no./ m^2)				Total weed dry weight (g/ m^2)	Weed smothering efficiency (%)	Grain yield		Maize equivalent yield (t/ha)	B:C ratio
	Grass	Broad-leaf	Sedge	Total			Maize (t/ha)	Green gram (t/ha)		
Irrigation										
0.70 IW/CPE	15.3	14.6	5.7	35.5	15.1	9.26	3.34	0.16	3.97	1.98
0.80 IW/CPE	9.9	7.4	6.2	23.6	10.9	34.16	3.60	0.22	4.40	2.25
0.90 IW/CPE	10.9	11.6	5.4	27.9	12.6	24.11	3.36	0.20	4.10	2.11
1.00 IW/CPE	15.9	15.5	7.3	38.7	16.6		2.79	0.16	3.38	1.66
LSD (P=0.05	5.48	3.96	1.62	6.31	4.92		0.09	0.31	0.12	
Inter-cropping										
Maize sole	23.1	23.9	10.1	57.1	23.3		4.17	0.0	4.17	1.94
Green gram sole	13.2	11.5	2.6	21.3	11.1	52.43	0.0	0.35	4.33	1.88
Maize + green gram 1:1	11.3	10.3	5.7	27.3	14.2	39.06	3.92	0.22	4.74	1.99
Maize + green gram 1:2	10.2	14.2	4.3	28.7	12.2	47.79	3.36	0.22	4.17	1.96
Maize + green gram 2:1	11.7	10.4	6.8	29.0	16.9	27.55	4.06	0.12	4.50	1.94
Maize + green gram 2:2	8.6	14.3	3.5	19.4	10.4	55.31	4.13	0.19	4.87	2.28
LSD (P=0.05)	2.74	3.01	2.02	4.52	2.26		0.34	0.17	0.08	

19.4/m^2 and weed dry weight (10.4 g/m^2) followed by sole green gram (21.3/ m^2 and 11.1 g/m^2). Higher weed infestation was recorded in IW/CPE ratio of 1.0 with weed density and dry weight values of 38.7/ m^2 and 16.6 g/m^2, respectively. Similarly, treatment with maize + green gram in 2:1 ratio recorded high weed infestation of corresponding values of 29.0 /m^2 and 16.9 g/m^2, respectively. The weed smothering efficiency was highest when irrigated at 0.8 IW/CPE among the main plot treatment in maize +green gram 2:2 ratio (55.31 %) followed by green gram sole (52.4%) among the sub-plot treatments. This was in agreement with Dwivedi *et al.* (2011)

Effect on crop

Irrigation treatment in the main plot has significant effect on grain yield of both maize and green gram. Highest grain yield of 3.6 t/ha in maize and 0.22 t/ha in green gram was recorded when irrigation was scheduled at 0.8 IW/CPE, which was significantly higher than all other irrigation schedules tested (Table 1).

Grain yield of maize in intercropping with green gram was statistically at par with its yield in pure stand (4.17 t/ha). The yield of green gram was reduced under intercropping than the sole crop (0.35 t/ha) in all the cases. This might be due to rate of reduction of plant population of maize and green gram in inter cropped plots than in their respective sole crops The result is in conformity with that of Singh *et al.* (2005). Intercropping of maize and green gram resulted in significant higher maize equivalent yield as compared to either of the sole crops. The highest maize equivalent yield (4.87 t/ha) was recorded in maize + green gram 2:2 ratio which was significantly superior over all other intercropping treatment followed by maize + green gram 1:1 ratio (4.74 t/ha). The highest B:C ratio was recorded at 0.80 IW/CPE (2.25) and with 2:2 planting pattern of maize + green gram (2.28).

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Weed management in no-tilled dribbling maize for small land holder

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ABSTRACT

A field experiment was carried out during winter (*Rabi*) seasons of 2012-13 and 2013-14 at research farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal with the objectives to study the weed control practices in no-tilled dibbling maize within rice residues. The experiment consisted of eight treatments, comprising of varying doses of 2,4-D (post-emergence treatment), atrazine with sequential application as pre-emergence and post-emergence treatment, pendimethalin followed by atrazine, weedy check and complete weed-free treatments, laid out in randomised block design (RBD) with four replications. Highest weed control efficiency and lowest weed index values were registered by atrazine 1.0 kg/ha as pre-emergence + atrazine 1.1 kg/ha as post-emergence. The dominant weed flora were the broad-leaved weeds *Polygonum persicaria, P. pensylvanicum, P. orientale,* and the grasses *Digitaria ciliaris, Setaria glauca.* Among the weed control practices, season long weed free condition recorded the highest grain/kernel yield of maize (9.52 and 10.6 t/ha) during both the years, which was statistically at par with atrazine 1.0 kg/ha as pre-emergence + atrazine 1.1 kg/ha as post-emergence (9.3 and 10.4 t/ha) and atrazine 0.75 kg/ha as pre-emergence + atrazine 1.1 kg/ha as post-emergence (9.07 and 10.12 t/ha). The atrazine 1.0 kg/ha as pre-emergence + atrazine 1.1 kg/ha as post-emergence gave maximum net return of (` 93,650/ha and ` 1,21,050/ha) and maximum net return per rupee invested (1.88 and 2.31).

Key words: Atrazine, Chemical control, No-tilled dibbling maize, Pendimethalin, Small land holder

Maize or corn (*Zea mays* L.) is the most versatile crop having wider adaptability under varied agro-climatic conditions with highest genetic yield potential among the cereals. Hence, it is referred to as 'Queen of Cereals' or 'Miracle Crop'. It is cultivated throughout the year in all states of country. In India, maize is the third most important food crops after rice and wheat. Currently, it is cultivated in India in an area of 8.49 mha with a production of 21.28 million ton and productivity of 2.51 t/ha (Rao *et al*., 2014). In this region of West Bengal, maize is generally cultivated at the terminal part of the winter season *i.e.* before the beginning of *pre-Kharif* (summer season). Severe infestation by weeds is considered as a major constraint in maize cultivation. Uncontrolled weeds in maize caused yield reduction in the range of 40 to 60% depending upon the intensity and types of weed flora (Sunitha and Kalyani 2012). Increased weed problems and other irreversible damage caused by conventional tillage practices led to the need of exploring alternate crop establishment techniques.

Conservation agriculture (CA) is now widely recognized as a viable concept for practicing sustainable agriculture. CA holds tremendous potential for all size of farm and agro-ecological system, but its adaptation is probably most urgently required by small land holder (FAO 2006). It has been the greatest challenge to bring the small land holder under conservation tillage practices as small fragmented lands became inaccessible for operating tractor driven 6 or 11 tynes zero tillage machines. Therefore, no-tilled dibbling crop establishment technique was taken into consideration for adopting conservation tillage practices in small fragmented lands dominated in these areas. In view of the importance of weed control in no-tilled condition, field experiment was conducted in no-tilled dibbling maize within rice anchor residues with the objectives to study the weed control practices in no-tilled dibbling maize and to work out the economics of maize cultivation.

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METERIALS AND METHODS

A field experiment was conducted during two consecutive winter (*Rabi*) seasons of 2012-13 and 2013-14 at research farm of Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal. The soil of the experiment was sandy loam in texture having a pH 5.45 with 0.62% organic carbon, low in available nitrogen (112.25 and 115.50 kg N/ha), medium in available phosphorus (18.21 and

17.50 kg P_2O_5 /ha) and low in available potassium (80.53 and 92.23 kg K_2O/ha) during both the year of experimentation. Eight treatments comprising of varying doses of 2,4-D (post-emergence treatment), atrazine with sequential application as pre-emergence and post-emergence treatment, pendimethalin followed by atrazine, weedy check and complete weed-free treatments were laid out in randomised block design (RBD) with four replications. 2,4-D sodium salt and pendimethalin (38.7% EC) was used during first year and 2,4-D ethyl-ester and pendimethalin (30% EC) was used during 2nd year of experimentation.

A small locally made narrow iron spade known as dibbler was used to open the hole/slot within rice anchor residue in which hybrid maize seeds (Variety *900 M Gold*) were dibbled manually at the depth of 6 cm at 60 x 30 cm spacing with the seed rate of 19 kg/ha. Glyphosate (1.5 kg/ha) was applied one week before sowing as pre-plant desiccators. Pre-sowing irrigation was given four days before sowing operation. The NPK ratio of 130:60:85 kg/ha was applied. Vermicompost 200 kg/ha, fertilizer mixture (10:26:26) 225 kg/ha, mixture of chloropyriphos (500 ml trade product) + rice husk (2 kg) + molasses (250 g) per 1333 m^2 were applied together with handful mixture at the time of dibbling. Urea was top-dressed in two split doses (113 kg/ha each) during 28-30 days after sowing (DAS) and 50-55 DAS. MOP (45 kg/ha) was also top dressed during 50-55 DAS along with final top dressing of nitrogenous fertilizer. A knapsack sprayer fitted with flat fan nozzle using 550 litres of water per hectare was used for spraying the herbicide. Weed population was taken by quadrate method and dry weight was done as per standard method. Data on weed dry weight was subjected to “x+1” square root transformation to normalize the distribution. The grain yield of maize was recorded at harvest from the net plot area. Economics of the treatments was computed based on prevalent market price.

RESULTS AND DISCUSSION

Effects on weeds

The experimental field was infested with grasses, sedges and broad-leaved weeds. The grasses *Cynodon dactylon*, *Setaria glauca, Digitaria ciliaris,* the broad-leaved weeds *Polygonum pensylvanicum, Polygonum orientale* and *Polygonum persicaria, Stellaria media, Stellaria aquatic, Oldenlandia diffusa, Hydrocotyl ranunculoides, Chenopodium album, Solanum nigrum, Physalis minima* and *Ageratum conyzoides* and the sedge *Cyperus rotundus,* were recorded in the experimental field during both the year of experimentation. Higher values of ‘Importance Value Index’ (IVI) and ‘Summed Dominance Ratio’ (SDR) of species like *Polygonum, Stellaria media, Oldenlandia diffusa, Digitaria ciliaris* and *Setaria glauca* at 35 DAS and 75 DAS indicated higher persistence and aggressive nature of these weeds during the crop growth. Other broad-leaved weeds like *S. aquatica, C. album, P. minima, S. nigrum, Oxalis corniculata* and *Hydrocotyl ranunculoides* and sedge *C. rotundus* recorded moderate values of these parameters indicating less aggressive nature of these weeds. The values of per cent contribution of total weed population also indicated dominance of *Polygonum* sp., *O. diffusa, S. glauca* and *D. ciliaris* during the crop growth (Table 1). Among the weed flora, broad-leaved weeds were more aggressive than that of grasses and sedges. The broad-leaved weeds *A. conyzoides, O. corniculata* and *H. ranunculoides* appeared only during 2nd year of experimentation at the later part of the crop growth indicating the invasion capacity of this weed in maize.

Among the weed control practices, the lower dose of atrazine (0.75 kg/ha) as pre-emergence treatment was effective in inhibiting the germination and emergence of grasses and broad-leaf weeds, however, its residual toxicity in controlling those weeds was comparatively lower than that of higher dose (1.0 kg/ha) of atrazine. Among the treatments, lowest dry matter of the weeds at 35 DAS and 75 DAS was recorded in atrazine 1.0 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence) treatment, which was at par with the treatment atrazine 0.75 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence). Pendimethalin with the formulation of 38.7% EC at the dose of 0.90 kg/ha was less effective to control grasses and broad-leaved weeds during 1st year of experimentation, however, during 2nd year of experiment, pendimethalin with formulation of 30% EC at the dose of 0.70 kg/ha showed higher level of control in terms of reduction on weed dry weight. This result showed that weed control capacity of pendimethalin varied in variation of its commercial formulation. It was observed in the experiment that the broad-leaved weeds *Polygonum* sp., *S. media, P. minima* and *S. nigrum* showed tolerance against the action of 2,4-D (Mukherjee *et al*., 2011). The results revealed that these weeds were not controlled effectively by the application of both formulations of 2,4-D (2,4-D sodium salt and ethyl ester) with the doses of 0.50 kg/ha, 0.75 kg/ha and 1.0 kg/ha. Highest weed control efficiency value and lowest weed index value were recorded by the treatments atrazine 1.0 kg/ha (pre-emergence) + atrazine kg/ha (post-emergence) closely followed by the treatment atrazine 0.75 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence) indicated the selective nature of his herbuicde in controlling weeds without causing phytotoxicity on maize plant (Table 2). Kumar *et al.* (2012) also reported that atrazine followed by atrazine resulted in highest weed control efficiency of 80.3% which was followed by sequential application of pendimethalin and atrazine. These findings also corroborate with the findings of Deshmukh *et al.* (2014), Gopinath *et al.* (2008) and Madhavi *et al.* (2014). Advancement of sowing to last week of November in 2nd year of experimentation improved weed control efficiency to the tune of 5.34% at 35 DAS and 11.1% at 75 DAS on the basis of weed growth in weedy check treatment. Weeds in weedy check treatment have the capacity to cause yield reduction to the tune of 60.7 to 62.3%.

Effect on yield

Among weed control treatments, season long weed free condition registered highest value of grain yield (9.6 and 10.6 t/ha), which was closely followed by the treatment atrazine 1.0 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence) (9.3 and 10.4 t/ha) and the treatment atrazine 0.75 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence) (9.1 and 10.1 t/ha) without having any significant difference among each other (Table 2). Even though the treatments atrazine 1.0 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence) and atrazine 0.75 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence) were statistically at per among each other in terms of grain yield, however, 2.48 to 2.75% yield increment was recorded by increasing dose of atrazine from 0.75 kg/ha to 1.0 kg/ha as pre-emergence coupled with atrazine 1.1 kg/ha as post-emergence. Yield increment 11.65% was recorded due to advancement of sowing during 2nd year of experimentation. Yield increment to the tune of 15.41% was registered by changing the pendimethalin from 38.7% EC formulation of 0.90 kg/ha to 30% EC formulation of 0.70 kg/ha coupled with atrazine 1.1 kg/ha as post-emergence and advancement of sowing to last week of November (Table 2).

Economic impact

The treatment atrazine 1.0 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence), gave the maximum net return (₹93,650 and 1,21,050/ha) and net return per rupee invested (1.88 and 2.31) which was followed by the treatment atrazine 0.75 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence) (90,960 and 1,17,500/ha) (Table 2). Even though the treatments atrazine 1.0 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence) and atrazine 0.75 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence) were statistically at per among each other in terms of grain yield, however, more investing as input cost to the tune of ` 180 to 195.00/ha for increasing the dose of atrazine from

Table 1. Relative density (RD), relative frequency (%), importance value index (IVI) and summed dominance ratio (SDR) and per cent of total weed population of weed flora appeared in weedy check treatment

Weed species	Relative Density (RD)				Relative Frequency (%)				Importance Value Index (IVI)				Summed Dominance Ratio (SDR)				Per cent of total Weed population (%)			
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
	35 DAS	35 DAS	75 DAS	75 DAS	35 DAS	35 DAS	75 DAS	75 DAS	35 DAS	35 DAS	75 DAS	75 DAS	35 DAS	35 DAS	75 DAS	75 DAS	35 DAS	35 DAS	75 DAS	75 DAS
Polygonum persicaria	19.3	17.2	15.7	14.33	9.30	7.84	9.52	7.41	28.7	25.0	25.25	21.74	14.33	12.50	12.62	10.87	19.35	17.16	15.73	14.33
Polygonum pensylvanicum	16.8	14.2	11.3	10.19	9.30	7.84	9.52	7.41	26.1	22.0	20.81	17.60	13.07	11.03	10.41	8.80	16.85	14.21	11.29	10.19
Polygonum orientale	8.24	8.58	7.66	7.96	9.30	7.84	9.52	7.41	17.5	16.4	17.19	15.37	8.77	8.21	8.59	7.68	8.24	8.58	7.66	7.96
Stellaria media	11.5	12.9	7.26	9.24	9.30	7.84	9.52	7.41	20.8	20.7	16.78	16.64	10.39	10.36	8.39	8.32	11.47	12.87	7.26	9.24
Stellaria aquatica	4.30	5.90	4.44	2.55	6.98	5.88	7.14	3.70	11.3	11.8	11.58	6.25	5.64	5.89	5.79	3.13	4.30	5.90	4.44	2.55
Oldenlandia diffusa	10.0	10.5	7.66	7.01	9.30	5.88	9.52	7.41	19.3	16.3	17.19	14.41	9.67	8.17	8.59	7.21	10.04	10.46	7.66	7.01
Solanum nigrum	4.30	4.83	3.23	3.82	4.65	5.88	4.76	7.41	8.95	10.7	7.99	11.23	4.48	5.35	3.99	5.61	4.30	4.83	3.23	3.82
Physalis minima	2.87	3.22	3.23	3.50	6.98	7.84	4.76	7.41	9.84	11.1	7.99	10.91	4.92	5.53	3.99	5.46	2.87	3.22	3.23	3.50
Oxalis corniculata	0.00	0.00	4.44	5.10	0.00	3.92	0.00	3.70	0.00	3.92	4.44	8.80	0.00	1.96	2.22	4.40	0.00	0.00	4.44	5.10
Chenopodium album	2.87	4.02	1.61	1.91	4.65	3.92	4.76	3.70	7.52	7.94	6.37	5.61	3.76	3.97	3.19	2.81	2.87	4.02	1.61	1.91
Ageratum conyzoides	0.00	0.00	4.84	2.55	0.00	5.88	0.00	7.41	0.00	5.88	4.84	9.96	0.00	2.94	2.42	4.98	0.00	0.00	4.84	2.55
Hydrocotyl ranunculoides	0.00	0.00	6.05	2.55	0.00	3.92	0.00	5.56	0.00	3.92	6.05	8.10	0.00	1.96	3.02	4.05	0.00	0.00	6.05	2.55
Cyperus rotundus	3.23	3.22	4.44	5.41	6.98	5.88	7.14	5.56	10.2	9.10	11.58	10.97	5.10	4.55	5.79	5.48	3.23	3.22	4.44	5.41
Digitaria ciliaris	6.45	7.24	8.06	8.92	9.30	7.84	9.52	7.41	15.7	15.1	17.59	16.32	7.88	7.54	8.79	8.16	6.45	7.24	8.06	8.92
Setaria glauca	5.73	5.90	7.26	10.19	9.30	7.84	9.52	7.41	15.0	13.7	16.78	17.60	7.52	6.87	8.39	8.80	5.73	5.90	7.26	10.19
Cynodon dactylon	4.30	2.41	2.82	4.78	4.65	3.92	4.76	3.70	8.95	6.33	7.58	8.48	4.48	3.17	3.79	4.24	4.30	2.41	2.82	4.78

Y1 = First year (2012-13). Y2 = Second year (2013-14). DAS- Days after sowing

Table 2. Weed control efficiency, weed index, grain/kernel yield and economics of maize as influenced by different weed management treatments

Treatment	Weed control efficiency (%) at 35 DAS		Weed control efficiency (%) at 75 DAS		Weed index (%)		Grain yield (t/ha)		Net return (×10^3 ₹/ha)		Net return per rupee invested (₹)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
2,4-D 0.50 kg/ha	3.17	0.80	38.5	42.8	47.21	45.00	5.03	5.83	35.11	51.23	0.73	1.00
2,4-D 0.75 kg/ha	2.44	1.31	47.4	53.7	45.22	43.41	5.21	5.96	38.57	52.91	0.80	1.02
2,4-D 1.00 kg/ha	2.85	1.17	48.6	56.0	43.63	42.45	5.33	6.05	43.76	54.09	0.90	1.04
Pendimethalin {0.90 kg/ha (Y1) 0.70 kg/ha (Y2)}+ atrazine 1.1 kg/ha	61.65	68.63	63.4	74.3	16.23	12.82	7.95	9.18	75.05	101.53	1.49	1.92
Atrazine 0.75 kg/ha+ atrazine 1.1 kg/ha	69.31	73.39	71.1	77.4	4.54	3.39	9.08	10.12	90.96	117.50	1.83	2.25
Atrazine1.00 kg/ha+ atrazine 1.1 kg/ha	74.37	77.03	76.7	80.4	2.05	1.25	9.30	10.40	93.65	121.05	1.88	2.31
Weedy check	00.0	00.0	00.0	00.0	60.74	62.34	3.76	3.95	19.71	27.10	0.41	0.53
Complete weed-free	100	100	100	100	00.0	00.0	9.56	10.64	-	-	-	-
LSD (P=0.05)			-	-	-	-	0.97	1.37	-	-	-	-

Y1 = First year (2012-13). Y2 = Second year (2013-14). DAS = Days after sowing. Minimum support price in the year 2012-13- ₹117/t . Minimum support price in the year 2013-14- 131/t.

0.75 kg/ha to 1.0 kg/ha resulted in obtaining more net return to the tune of ` 2,689 to ` 3,550/ha. More net return to the tune of ` 27,400/ha was obtained during 2nd year of experimentation in the treatments atrazine 1.0 kg/ha (pre-emergence) + atrazine 1.1 kg/ha (post-emergence) and this was mainly due to higher minimum support price, higher grain yield because of advancement of sowing and better weed control.

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Post-emergence herbicides for weed management in groundnut

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ABSTRACT

A field experiment was conducted at Agricultural Research Station, Kawadimatti, Karnataka during *Kharif* 2012 and 2013 to study the efficacy of post-emergence herbicides for weed management in groundnut. The trial comprised of eight treatments, out of which five treatments were of post-emergence herbicides, *viz*. quizalofop-ethyl, propaquizafiop, imazethapyr, chlorimuron-ethyl, fenoxaprop-p-ethyl. These were compared with, pre-emergence spray of pendimethalin weed free and weedy treatments. Among the post-emergence herbicides, significantly higher pod yield (2.01 t/ha) was recorded with imazethapyre, which was at par with quizalofop-ethyl (1.91 t/ha) and propaquizafop (1.87 t/ha). Imazethapyre also recorded higher net return (Rs/ha) and B:C ratio. Higher pod yield of these treatments was due to significantly lower total weeds density, weed biomass and higher weed control efficiency.

Key words: Economics, Groundnut, Post-emergence herbicides, Weed control efficiency, Weed index

Groundnut is important oil, food and forage crop of the country. India is the second largest producer of groundnut in the world. Among different constraints that limit the productivity of groundnut, weed menace is one of the serious bottlenecks (Chaitanya *et al.* 2012). The weeds emerge fast and grow rapidly competing with the crop severely for the resources namely nutrients, sunlight, and space, soil moisture and reduce the crop yield. Competitional stress of weeds exerts reduction in pod yield to the extent of 17-84% (Guggari *et al.* 1995). Thus weed management is essential to get optimum crop yield.

At present several herbicidal formulations are available in the market used as pre- and post-emergence herbicides for controlling weed complex. The pre-emergence herbicides like pendimethalin were found to be effective in controlling the weeds during early stages of groundnut crop. Use of these selective herbicides as pre-emergence herbicides provide only the initial weed control and often needs integration with one manual weeding for effective weed control. In some cases during sowing time, farmers give first priority to sow the crop rather than to use herbicides for controlling weeds. Under such situations post-emergence herbicides play an important role in managing weeds during the cropping period. The present experiment was conducted with an objective to identify post-emergence herbicides for effectively managing weeds in groundnut crop.

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MATERIALS AND METHODS

A field experiment was conducted at Agricultural Research Station, Kawadimatti, Karnataka. The soil was red sandy loam with normal soil reaction (7.53) and electrical conductivity (0.14), low in organic carbon (0.3) and available N (142 kg/ha), medium in available P_2O_5 (51 kg/ha) and K_2O (120 kg/ha).

The experiment was laid out in randomized complete block design replicated thrice comprised of eight treatments, *viz*. pendimethalin 750 g/ha as pre-emergence herbicide, post-emergence herbi-cides quizalofop-ethyl 25 g/ha, propaquizafop 50 g/ha, imazethapyr 100 g/ha, chlorimuron-ethyl 9 g/ha, fenoxaprop-p-ethyl 9.3 g/ha and a control plot (recommended practice - two hand weeding at 20 and 40 DAS along with intercultivation operation) and weedy check treatments. The experiment crop was sown on 25th July and 20th July during 2012 and 2013, respectively. Groundnut local variety (*TMV-2*) was sown at 30 x 10 cm spacing. Recommended dose of fertilizer (25:50:25 kg of N.P.K/ha) along with gypsum 500 kg/ha and Zn 25 kg/ha were applied at basal. Pre-emergence herbicide, pendimethalin 700 g/ha was sprayed on the day of sowing. Post-emergence herbicides, *viz.* quizalofop-ethyl 25 g/ha, propaquizafop 50 g/ha, imazethapyr 100 g/ha, chlorimuron-ethyl 9 g/ha, fenoxaprop-p-ethyl 9 g/ha were applied at 20 days after crop sowing (DAS). It coincides with 2-4 leaf stage of weeds. Total spray solution used was 500 l/ha. The knapsack sprayer fitted with flat fan nozzle was used for the herbicide spray. These treatments were compared with recommended practice two hand weeding at 20 and 40 DAS with inter cultivation and weedy check. The weed density and weed biomass from one m^2 was recorded before herbicides spray and at 15, 30 and 45 days after application.

For bio-efficacy observations, three spots were selected at random and marked with pegs in each plot. Total weed density of major weed species was recorded using 0.25 m^2 quadrant in peg marked areas before herbicide application and at 15, 30 and 45 DAS, and it was converted to number of weeds per meter square area. Weed biomass was also recorded from each plot from 0.25 m^2 quadrant and computed to gram per square meter area. At the end of cropping season, yield was recorded from net plot area and computed to per hectare.

Cost of cultivation, gross return and net return were calculated based on the prevailing price of inputs and outputs. Benefit cost ratio was calculated on the basis of gross return divided by the cost of cultivation. The weed density and weed biomass data were square-root transformed.

RESULTS AND DISCUSSIONS

Weed flora

The weed flora in experimental plots comprised of dicots, grasses, sedges and broad-leaf weeds. Major weeds infested were *Tridax* sp., *Leptocloa* sp., *Mulugo* sp., *Phyllanthns* sp., *Cyprus* sp., *Beorhaavia* sp., *Commelina* sp.,*Cyperus rotandus*,*Cynodon doctylon, Digera arvensis etc*. In the first year, the selected experimental plot had more grassy weeds. Whereas in second year, the selected experimental plot had more broad-leaf weeds.

The observations on weed density at 15, 30 and 45 days after spraying of post-emergence herbicides (Table 1) revealed that imazethapyr and chlorimuron-ethyl recorded significantly lower broad-leaf weeds density over the rest of the treatments. In case of grassy weeds, lower weed density was recorded with quizalofop-ethyl which was at par with propaquizafop followed by imazethapyr. These results indicate that imazethapyr was effective in controlling both broad-leaf weeds and grassy weeds, which was in conformity with observations of Kelly *et al* (1998). Quizalofop-ethyl and propaquizafop were effective in controlling only grassy weeds. Significantly lower weed density was recorded with post-emergence spray of imazethapyr (16.76, 14.20 and 14.51/m^2) and it was at par with quizalofop-ethyl (19.26,16.98 and18.10/m^2) and propaquizafop (22.17,18.31 and 19.41/m^2) at 15, 30 and 45 days after application of herbicide. Since imazethapyr was effective in reducing weeds density significantly, it resulted in significant reduction of total weeds biomass. These results were in conformity with those of Sangeetha *et al.* (2012).

Among the post-emergence herbicide, imazethapyr recorded significantly higher weed control efficiency (66.6, 74.2 and 72.2) followed by quizalofop-ethyl (66.4, 69.2 and 67.4) and propaquizafop (60.0, 68.1 and 66.6) at 15, 30 and 45

Table 1. Weed density and total weed biomass at different stages as influenced by herbicides in groundnut (pooled data)

Treatment	Broad-leaf weed density (no/m^2)				Grassy weed density (no/m^2)				Total weed density (no/m^2)				Total weed biomass (g/m^2)			
	Before	15 DAA	30 DAA	45 DAA	Before	15 DAA	30 DAA	45 DAA	Before	15 DAA	30 DAA	45 DAA	Before	15 DAA	30 DAA	45 DAA
Pendimethalin	1.22 b (1.56)	1.35 bc (1.93)	1.85 b (2.96)	1.81 b (3.33)	1.70 b (3.00)	1.92 d (3.69)	1.99 c (3.95)	2.11 c (4.46)	2.06 b (4.56)	2.33 d (5.61)	2.61 d (6.91)	2.79 d (7.78)	1.93 b (3.59)	1.98 d (3.91)	2.12 d (4.62)	2.24 c (5.32)
Quizalofop-ethyl	2.91 a (8.46)	3.83 a (14.78)	3.85 a (14.40)	3.89 a (15.18)	5.65 a (32.04)	2.11 cd (4.48)	1.59 c (2.59)	1.71 c (2.92)	6.35 a (40.50)	4.37 c (19.26)	4.12 c (16.98)	4.24 c (18.10)	3.95 a (15.23)	4.06 c (16.43)	3.95 c (15.66)	4.07 b (16.63)
Propaquizafop	2.81 a (7.88)	3.83 a (14.67)	3.92 a (14.88)	3.91 a (15.38)	5.69 a (32.13)	2.73 c (7.50)	1.82 c (3.43)	1.89 c (3.76)	6.33 a (40.01)	4.70 c (22.17)	4.26 c (18.31)	4.34 c (19.14)	3.98 a (15.40)	4.36 c (19.22)	3.99 c (16.08)	4.09 b (16.89)
Imazethapyr	2.95 a (8.81)	1.94 b (3.85)	1.96 b (3.47)	1.94 b (3.90)	5.75 a (32.79)	3.58 b (12.91)	3.27 b (10.73)	3.25 b (10.62)	6.69 a (45.27)	4.90 c (16.76)	3.75 c (14.20)	3.80 cd (14.51)	4.17 a (16.93)	3.83 c (14.74)	3.50 c (12.33)	3.65 b (13.44)
Chlorimuron-ethyl	3.00 a (8.98)	1.83 b (3.52)	1.91 b (3.17)	1.83 b (3.43)	5.55 a (30.77)	5.72 a (32.92)	5.84 a (34.20)	5.90 a (35.04)	6.28 a (39.75)	6.03 b (36.44)	6.09 b (37.37)	6.18 b (38.47)	4.00 a (15.54)	5.62 b (31.54)	5.85 b (34.25)	6.02 a (36.31)
Fenoxaprop-p-ethyl	2.95 a (8.73)	4.00 a (16.05)	4.19 a (17.05)	(4.18 a 17.55)	5.87 a (33.97)	6.00 a (36.24)	6.05 a (36.60)	6.11 a (37.43)	6.54 a (42.70)	7.22 a (52.29)	7.32 a (53.65)	7.40 a (54.98)	4.08 a (16.13)	6.64 a (44.19)	6.85 a (46.95)	6.89 a (47.51)
Control	0.74 b (0.59)	0.91 c (0.86)	0.95 c (0.46)	0.93 c (0.96)	1.11 b (0.85)	1.02 e (1.09)	0.79 d (0.68)	0.88 d (0.85)	1.17 b (1.44)	1.29 e (1.95)	1.02 e (1.14)	1.22 e (1.80)	0.97 c (0.49)	1.12 d (1.36)	1.07 e (1.17)	1.16 d (1.54)
Weedy check	2.93 a (9.02)	3.93 a (15.77)	4.19 a (17.24)	4.19 a (17.74)	5.84 a (33.67)	5.97 a (36.29)	6.08 a (37.44)	6.13 a (38.11)	6.42 a (42.68)	7.14 a (52.06)	7.33 a (54.68)	7.40 a (55.84)	4.14 a (17.17)	6.64 a (45.65)	6.85 a (47.98)	6.91 a (48.54)
LSD (P=0.05)	0.53	0.61	0.641	0.647	0.985	0.798	0.756	0.786	1.144	1.013	0.991	1.039	0.79	0.95	0.958	0.976

*DAA-Days after application of post emergence herbicides, figures in the parenthesis are the original values and subjected to square root transformation

Table 2. Weed control efficiency (%), weed index (%), yield and economics as influenced by herbicides in groundnut (pooled data)

Treatment	Weed control efficiency (%)			Weed index (%)	Pod yield (t/ha)	Haulm yield (t/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C ratio
	15 DAA	30 DAA	45 DAA						
Pendimethalin	91.2 a	90.0 a	88.5 a	3.9 e	2.14 a	3.45 a	82.53 a	49.71 ab	2.53 a
Quizalofop-ethyl	66.4 b	69.3 b	67.4 b	14.2 cd	1.91 a	3.28 ab	74.77 a	41.40 b	2.25 a
Propaquizafop	60.0 b	68.1 b	66.6 b	15.9 c	1.87 a	3.26 ab	73.47 a	41.28 b	2.29 a
Imazethapyr	66.6 b	74.2 b	72.2 b	9.9 d	2.01 a	3.32 ab	76.48 a	43.47 ab	2.32 a
Chlorimuron-ethyl	29.3 c	27.3 c	24.6 c	36.4 b	1.39 b	2.77 bc	54.09 b	22.96 c	1.74 bc
Fenoxaprop-p-ethyl	3.6 d	2.4 d	2.3 d	46.4 a	1.19 b	2.53 c	46.29 b	15.30 d	1.50 c
Control	96.9 a	97.5 a	97.0 a	0 e	2.24 a	3.54 a	85.78 a	46.26 a	2.18 ab
Weedy check	0.0 d	0.0 d	0.0 d	48.8 a	1.14 b	2.36 c	44.65 b	14.43 d	1.48 c
LSD (P=0.05)	11.28	12.16	11.31	4.81	0.39	0.69	1.48	7.43	0.45

DAA-Days after application of herbicides, market price of groundnut pod: 2012- ` 450/t, 2013- ` 310/t

DAA. Significant reduction in total weeds biomass by these treatments might have contributed for higher weed control efficiency over rest of post-emergence herbicides.

Control (2 HW + IC) plot has recorded significantly lower total weed density, total weed biomass and higher weed control efficiency over rest of the treatments and it was followed by pre-emergence herbicide pendimethalin (along with one intercultivation). Whereas weedy check recorded significantly higher total weed density and total weed biomass and lower weed control efficiency.

Yield and economics

Pod yield was significantly influenced by post-emergence herbicides (Table 2). Pod yield of groundnut recorded significantly higher in weed free plot (2.24 t/ha). Among the post-emergence herbicides imazethapyr recorded higher pod yield (2.01 t/ha). These results were in concurrence with those of Chaitanya *et al.* (2012), whose higher seed yield of groundnut by effective post-emergence herbicides was due to effective control of grassy and broad-leaf weeds.

Two hand weeding and one intercultivation treatments have recorded significantly higher yield (2.24 t/ha) which was at par with pre-emergence herbicide treatment pendimethalin (2.14 t/ha) and post-emergence imazethapyr (2.01), quizalofop-ethyl (1.91 t/ha) and propaquizafop (1.87 t/ha). Similar trend was noticed in case of haulm yield end gross return.

Net return (` 49707/ha) and benefit cost ratio (2.53) was recorded significantly higher in treatment with pre-emergence spray of pendimethalin followed by post-emergence spray of imazethapyr (` 43474/ha and 2.32) as the higher pod yield was achieved with lower cost of cultivation by these treatments. Net return and benefit cost ratio in quizalofop-ethyl (` 41397/ha and 2.25) and propaquizafop (` 41281/ha and 2.29) treatments were at par with imazethapyr treatment. Sasikala *et al.* (2004) reported highest net return with post-emergence application of imazethapyr after pre-plant incorporation of fluchloralin in groundnut crop. Significantly lower pod yield, net return and B:C ratio was recorded in treatments with weedy check and it was at par with post-emergence application of chlorimuron-ethyl and fenoxaprop-p-ethyl as they failed to effectively control the weeds. It may be concluded that imazethapyr 100 g/ha as post-emergene application can manage both grassy as well as broad-leaf weeds and results in higher yield and net returns of groundnut.

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Sedges management in bottle gourd with halosulfuron-methyl

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ABSTRACT

A field experiment was conducted to evaluate the efficacy of halosulfuron-methyl for the control of *Cyperus* spp. in bottle gourd. The treatments constituted of halosulfuron-methyl at two doses (52.5 and 67.5 g/ha) applied at 3-4 leaf stages of sedges, which was compared with recommended dose of metribuzin (490 g/ha) as pre-emergence, two hand weeding (20 and 35 DAS) and unweeded check. The results revealed that all the weed control treatments significantly reduced *Cyperus* spp. density as compared to unweeded check except metribuzin 490 g/ha. The lowest weed biomass of *Cyperus* spp. was recorded with application of halosulfuron-methyl at higher dose (67.5 g/ha) which was significantly lower than halosulfuron-methyl 52.5 g/ha and metribuzin 490 g/ha. Significantly highest fruit yield of bottle gourd was recorded with application of halosulfuron-methyl 67.5 g/ha than other treatments. The herbicide tested in this study did not show any adverse effect on germination and grain yield of succeeding wheat crop.

Key words: Bottle gourd, *Cyperus*, Effect on succeeding crop, Halosulfuron-methyl, Weed control efficiency

Bottle gourd (*Lagenaria siceraria*) is a commonly grown vegetable crop of India and belongs to family Cucurbitaceae. It is cultivated in an area of about 0.10 million ha with a production and productivity of 1.82 mt and 18.2 t/ha, respectively (Anonymous 2015). Amongst many other reasons for its lower productivity, poor weed management is one of the crucial factors as due to slower early growth and close canopy structure, the bottle gourd faces severe competition from weeds, particularly from the perennial sedges resulting in huge yield losses. In some studies, losses in fruit yield of bottle gourd due to weeds were estimated up to 37 - 41% (DWSR 2013, Dash and Mishra 2014) as weeds pose a major biotic constraint in the crop culture. Socioeconomic risk in labour cost and availability warrant for alternate effective and economic weed control practices with inclusion of effective herbicides in these vegetable production systems. Infestation of problem weeds like *Cynodon dactylon* and *Cyperus rotundus* among other associated weeds is a major concern in these crops. The effect of these associated weeds has been so devasting in certain cases that leading to complete crop failure. Therefore, weed control at early crop stage is important to enhance the economic yield of the crop. Halosulfuron-methyl, a relatively new molecule is known to be very effective against sedges (Rathika *et al.* 2013). However, no information is available on use of halosulfuron-methyl on the bottle gourd in the state of Jammu and Kashmir; hence the present investigation was carried out.

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MATERIALS AND METHODS

A field experiment was conducted during *Kharif* seasons of 2012 and 2013 at the research farm of Sher-e-Kashmir University of Agricultural Sciences & Technology of Jammu, (J&K) to evaluate the bio-efficacy of post-emergence halosulfuron-methyl (75% WG) for the control of *Cyperus* spp. in bottle gourd and on succeeding crop wheat. The soil of the experimental field was sandy clay loam in texture. The experiment was laid out in randomized block design with 5 treatments, *viz*. halosulfuron-methyl 52.5 and 67.5 g/ha, pre-emergence metribuzin 490 g/ha, farmer's practice (2 HW at 20 and 35 DAS) and untreated control with four replications. The dose of halosulfuron-methyl 135 g/ha was applied only for residual study. *Punjab Komal* variety was sown on 9th of June, 2012 in first year and 21st of June, 2013 in second year of experimentation at 45 cm spaced rows within row to row and plant to plant. The recommended dose of N:P:K was applied at 100 kg N, 50 kg P_2O_5 and 50 kg K_2O/ha with source of urea, DAP and MOP. The efficacy of halosulfuron-methyl was worked out only against *Cyperus* spp. by eliminating other weeds, *viz.* grassy and broad-leaved weeds (BLWs). At 15 days after sowing of crop, *viz.* at 3-4 leaf stage of *Cyperus* spp. halosulfuron-methyl was sprayed on bottle gourd and observations on *Cyperus* spp. *i.e* weed density, weed biomass and weed control efficiency (WCE) were recorded at 20 and 35 days after application of herbicidal treatments. Experimental crop was raised by using recommended package of practices other than weed control. The weed control efficiency was calculated by using formula given by Mishra and Mishra (1997). The values with respect to density and biomass of weed were subjected to square root transformation $(\sqrt{x+1})$ as described by Bartlett (1947) and analyzed statistically.

RESULTS AND DISCUSSION

Effect on weed density and biomass

On the basis of two years study, it was observed that out of the total weed density in weedy plot, *Cyperus rotundus* (43.9%) and *Cyperus iria* (28.5%) were found to be the most dominating weeds comprising of 72.4% of the population (Table 1) followed by narrow-leaf weeds (24%) *viz.* *Echinochloa crusgalli* (12.2%), *Setaria glauca* (11.8%) and *Commelina benghalensis* (3.6%). At 20 days after application of treatments, all the weed control treatments significantly reduced the density of *Cyperus* spp. than unweeded control except metribuzin 490 g/ha in both the years. Amongst the various weed management treatments, remarkably highest per cent control of *Cyperus* spp. was recorded with application of halosulfuron-methyl at higher dose (67.5 g/ha) in both the years of experimentation (Table 2). Higher dose of halosulfuron-methyl (67.5 g/ha) recorded significantly lowest density of *Cyperus* spp. as compared to rest of the herbicidal treatments. A similar trend was also obtained by the weed control treatments on *Cyperus* spp. at 35 DAT except that weed density slightly increased probably owing to the fact that some weeds might have emerged at later stages. Application of halosulfuron-methyl 67.5 g/ha significantly reduced the dry matter accumulation of *Cyperus* spp. as compared to rest of the herbicidal treatments at both stages 20 and 35 DAT during both the years of experimentations. These results were in close conformity with the findings of Rathika *et al.* (2013) and Meher *et al.* (2013). Application of halosulfuron-methyl at 67.5 g/ha also recorded highest weed control efficiency at both the stages followed by farmer's practice (2 HW) and lower dose of halosulfuron-methyl (52.5 g/ha) (Table 3). This might be due to reducing the population as well as dry matter accumulation of *Cyperus* spp. which resulted increased weed control efficiency with halosulfuron application (Rathika *et al.* 2013).

Table 1. Relative weed density in weedy plot at 20 DAS

Weed species	Weed intensity/m^2 2012	2013	Average (no.)	Average (%)
Sedges				
Cyperus rotundus	50	47	48.5	43.9
Cyperus iria	32	31	31.5	28.5
Narrow leaf weeds				
Echinochloa crusgalli	17	10	13.5	12.2
Setaria glauca	20	6	13.0	11.8
Broad leaf weeds				
Commelina benghalensis	05	03	4.0	3.6
Total	124	97	110.5	100.0

Effect on crop

All herbicidal treatments except for metribuzin 490 g/ha in 2013 gave significantly higher fruit yield as compared to unweeded control during both the years. Among different herbicidal treatments, application of halosulfuron-methyl 67.5 g/ha

Table 2. Effect of different herbicides against *Cyperus* spp. in bottle gourd

Treatment	Dose (g/ha)	*Cyperus* spp./m^2 Pre-treatment 2012	Pre-treatment 2013	20 DAA 2012	20 DAA 2013	Mean% control over pre-treatment	35 DAA 2012	35 DAA 2013	Mean% control over pre-treatment
Halosulfuron-methyl	52.5	9.12 (82)	9.02 (80)	5.30 (27)	5.13 (25)	67.6	5.39 (28)	5.35 (28)	65.60
Halosulfuron-methyl	67.5	8.89 (79)	8.76 (76)	2.24 (4.1)	2.23 (4.0)	94.8	3.07 (8.5)	3.08 (8.5)	91.98
Metribuzin*	490	9.04 (81)	8.51 (71)	9.6 (92)	9.14 (82)	-14.8	10.08 (101)	9.90 (97)	-30.17
Farmer's Practice (2 hand weeding)	20 and 35 DAS	8.86 (78)	8.62 (73)	6.04 (35)	6.47 (41)	49.3	6.48 (41)	6.08 (36)	49.17
Untreated control	-	9.02 (80)	9.09 (82)	9.95 (98)	9.87 (96)	-20.3	10.63 (112)	10.46 (108)	-36.45
LSD (P=0.05)		NS	NS	2.09	1.21	-	2.38	1.91	-

DAS: Days after sowing, DAA: Days after application of treatment, Figures in parentheses are original values and subjected to square root transformation $(\sqrt{x+1})$, *Before application of halosulfuron-methyl

Table 3. Dry weed biomass, weed control efficiency against *Cyperus* spp. and fruit yield of bottle gourd in different herbicidal treatments

Treatment	Dose (g/ha)	*Cyperus* dry biomass (g/m^2)				Mean weed control efficiency (%)		Fruit yield (t/ha)	
		20 DAA		35 DAA					
		2012	2013	2012	2013	20 DAA	35 DAA	2012	2013
Halosulfuron-methyl	52.5	4.26 (17.31)	4.09 (15.70)	5.15 (25.49)	5.22 (26.27)	68.3	63.9	18.70	16.85
Halosulfuron-methyl	67.5	1.22 (0.53)	1.24 (0.55)	1.95 (2.80)	1.97 (2.89)	99.0	96.0	20.10	19.05
Metribuzin	490	6.71 (44.4)	6.30 (38.77)	7.36 (53.53)	7.37 (53.34)	20.1	25.6	16.00	12.00
Farmer's practice (2 hand weeding)	20 & 35 DAS	2.71 (6.38)	2.67 (6.14)	2.96 (7.79)	2.60 (5.76)	88.0	90.6	18.60	17.00
Untreated control	-	7.21 (51.22)	7.35 (52.98)	8.59 (73.12)	8.46 (70.52)	-	-	14.05	11.50
LSD (P=0.05)		3.01	0.67	3.14	0.60	-		1.31	0.69

DAS: Days after sowing, DAA: Days after application treatment, Figures in parentheses are original values and subjected to square root transformation $(\sqrt{x+1})$.

recorded significantly higher fruit yield than rest of the treatments which was 43 and 65 per cent higher over unweeded control during 2012 and 2013, respectively. The results were in close conformity with Dash and Mishra (2014). However, fruit yield obtained in lower dose of halosulfuron-methyl (52.5 g/ha) was found to be statistically at par with farmer's practice (Table 3). The higher fruit yield in halosulfuron-methyl 67.5 g/ha was due to efficient control of *Cyperus* spp. The results were in agreement with the findings of Singh *et al.* (2011) and Suganthi *et al.* (2013). Among the herbicidal treatments, lowest fruit yield was recorded with pre-emergence application of metribuzin 490 during both the years. Based on visual observations, the herbicidal treatments did not show any phytotoxic in bottle gourd. There was no residual effect on succeeding wheat crop by the herbicidal treatments. Germination of succeeding wheat crop ranged between 87 to 92 per cent. Also herbicides tested in this study produced almost similar grain yield of succeeding wheat crop even at a higher dose of halosulfuron-methyl 135 g/ha (Table 4). The result was also similar with the findings of Rathika *et al.* 2013.

Table 4. Effect of in different herbicidal treatments on wheat sown as follow-up crop

Treatment	Germination (%)		Yield (t/ha)	
	2012	2013	2012	2013
Halosulfuron- methyl 52.5 g/ha	90.0	87.0	2.57	2.65
Halosulfuron-methyl 67.5 g/ha	88.0	88.0	2.52	2.60
Halosulfuron-methyl 135 g/ha	92.0	90.0	2.58	2.70
Metribuzin* 490 g/ha	91.0	89.0	2.49	2.64
Farmer's practice (2 hand weeding) 20 and 35 DAS	89.0	88.0	2.50	2.71
Untreated control	88.0	87.0	2.51	2.69

DAS: Days after sowing; *Before application of halosulfuron-methyl

On the basis of two years of experimentation, it was concluded that post-emergence application of halosulfuron-methyl 67.5 g/ha applied at 3-4 leaf stage of sedges was most promising in controlling *Cyperus* spp.

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Weed management in berseem

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ABSTRACT

Experiments was conducted during *Rabi* season of three consecutive years from 2012 to 2015 to study the effect of weed management on forage and seed yield of berseem (*Trifolium alexandrinum* L.) in medium black soil. The treatment combinations were application of pre-emergence herbicides *viz*. pendimethalin and oxyflourfen and post-emergence herbicide, *viz*. imazethapyr in different proportion along with weedy check (control). Based on the pooled mean data for three years, it was revealed that green fodder, dry matter and crude protein yields (34.39, 4.53 and 0.81 t/ha respectively) were significantly higher in treatment combination of oxyflourfen 0.1 kg/ha + imazethapyr 0.1 kg/ha immediate after harvest of first cut. The same treatment combination recorded highest seed yield (0.47 t/ha) and straw yield (5.87 t/ha) with net monetary returns of ` 1,34,048/ha, benefit cost ratio of 3.43 and maize fodder equivalent yield of 72.68 t/ha. The lowest weed dry matter yield (0.05 t/ha) and highest weed control efficiency (80.97%) were recorded in same treatment combination.

Key words: Berseem, Forage yield, Seed yield, Weed management, Weed control efficiency

Berseem (*Trifolium alexandrium* L.), a potential winter forage legume, is one of the most popular crop in North, North-West and central parts of India. It is well known green forage crop to stimulate milk production in dairy animals. Due to its excellent and quick re-growing ability and long durational nutritious green fodder availability (November to April), the crop is grown under irrigated condition. Because of its slow growth in the initial stages, yield reduction in the crop on account of weeds is well documented. Weeds particularly *Cichorium intybus* found associated with berseem and give more computational stress by robbing the crop of essential nutrients, light, moisture and space (Thakur *et al.* 1990). Weed competition substantially reduces the green forage yield and consequently, it causes reduction up to 30-40% besides deteriorating quality of green forage, if not controlled during critical period of crop-weed competition (Jain 1998a). Therefore, there is need to create an environment that is detrimental to weeds and favourable to the crops. Physical methods of weed control are very costlier, labour intensive and sometimes it is not possible due to non availability of labours. Under such situation, chemical weed control offers a better alternative to manual weeding. Since, meager information is available on the comparative studies of different weed control practices in berseem, the present investigation was undertaken to evaluate the bio efficacy of herbicide alone or in combination with use of two different herbicides in sequence for managing the weeds in berseem.

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MATERIALS AND METHODS

Experiment was conducted at Central Research Station, Urulikanchan of BAIF, Pune during three consecutive years in *Rabi* 2012-13 to 2014-15 to study the effect of weed management on forage and seed yield of berseem (*Trifolium alexandrinum* L.). The soil of the experimental field was sandy clay in texture, low in available nitrogen (147 kg/ha), high in available phosphorus (43 kg/ha) and medium in available potassium (195 kg/ha). It was moderately alkaline in reaction (pH 7.29) with 0.59 dSm^{-1} electrical conductivity and organic carbon content was 0.52%. The experiment consisting of 10 treatments (Table 1) was laid out in randomized block design replicated thrice. The gross and net plot size was 4.0 x 3.0 m and 3.40 x 2.40 m respectively.

The treatment combinations were application of pre-emergence herbicides *viz*. pendimethalin, oxyflourfen and post-emergence herbicide, *viz*. imazethapyr in different proportion along with weedy check. Herbicides were sprayed with manually operated knapsack sprayer fitted with flat fan nozzle at spray. Pre-emergence herbicides were sprayed two days after sowing prior to emergence of weed as well as crop and post-emergence herbicide was applied immediately after harvest of Ist cut for fodder. The crop was given the recommended dose of fertilizers *i.e.* 20 kg N, 80 kg P_2O_5 and 40 kg K_2O/ha. The variety '*Wardan*' was sown at 30 cm apart by using seed rate of 25 kg/ha. First two cuts were taken for green forage and after harvesting of second cut for fodder, the crop was left for seed production. Harvesting of seed was done in the month of May. From each plot, representative fresh plant sample was taken in each cut to estimate the dry matter content for computing dry matter yield of fodder.

The weed count (monocot and dicot) and its dry weight were recorded from each plot by using a quadrate method (1.0 x 1.0 m) at harvest of last cut for seed. The weed count and weed dry weight values were transformed for statistical analysis. The weed control efficiency (WCE) and weed index (WI) were calculated as per the standard formula suggested by Gill and Vijayakumar (1969). Soil fertility status (pH, E.C., O.C., N, P and K) was determined using the standard methods described in (AOAC, 1995). The growth and yield observations were recorded at every cut and samples were analysed in laboratory by using standard analytical methods. The pooled data for three years was statistically analysed.

RESULTS AND DISCUSSION

Weed count

The data revealed that treatment of weedy check recorded significantly higher grasses (monocot), broad-leaved (dicot) and total weed count/m^2 at harvest than rest of the treatments (Table 1). However, significantly minimum monocot, dicot and total weeds (44.33, 6.33 and 50.66/m^2) were observed in treatment oxyflourfen 0.10 kg/ha followed by imazethapyr 0.10 kg/ha immediate after harvest of Ist cut. The results were in accordance with Pathan and Kamble (2012) and Pathan *et al.* (2013).

Weed dry weight

The weed dry weight was significantly higher (0.27 t/ha) in weedy check as compared to rest of the treatments. Whereas, treatment oxyflourfen 0.10 kg/ha followed by imazethapyr 0.10 kg/ha immediate after harvest of Ist cut registered the lowest (0.05 t/ha) dry weight of weed at harvest (Table 1). The results were in accordance with the findings of Jain (1998a), Tamrakar *et al.* (2002), Pathan and Kamble (2012) and Pathan *et al.* (2013).

Weed control efficiency

Pre-emergence application of oxyflourfen 0.10 kg/ha followed by post-emergence application of imazethapyr 0.10 kg/ha immediate after harvest of Ist cut recorded maximum (80.97 %) and significantly superior weed control efficiency over rest of the treatments. The higher weed control efficiency might be due to reduced dry weight of weeds in treatment oxyflourfen 0.10 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of Ist cut) as compared to weedy check (Table 1). This observation was in agreement of Stidham and Singh (1991), Jain (1998a), Tiwana *et al.* (2002), Pathan and Kamble (2012) and Pathan *et al.* (2013).

Prajapati *et al.* (2015) recorded that weed dry weight was significantly less (48.73 g/0.25 m^2) due to application of pendimethalin 1.0 kg/ha + imazethapyr 0.15 kg/ha applied immediate after 1st cut resulting in higher weed control efficiency (43.53%).

Table 1. Weed count, weed dry weight and weed control efficiency as influenced by different treatments in berseem crop

Treatment	Species wise weed count/m^2			Weed dry matter yield (t/ha)	Weed control efficiency (%)
	Monocot	Dicot	Total		
Pendimethalin 0.30 kg/ha	65.50	11.17	76.67	0.16	40.13
Pendimethalin 0.40 kg/ha	64.83	11.33	76.16	0.12	52.14
Pendimethalin 0.50 kg/ha	69.67	11.50	81.17	0.13	50.87
Oxyflourfen 0.10 kg/ha	59.50	8.17	67.67	0.11	59.07
Imazethapyr 0.10 kg/ha (immediate after harvest of Ist and IInd cut)	97.50	10.50	108.00	0.12	55.55
Oxyflourfen 0.10 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of Ist cut)	44.33	6.33	50.66	0.05	80.97
Pendimethalin 0.30 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of Ist cut)	63.00	10.67	73.67	0.11	57.61
Pendimethalin 0.40 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of Ist cut)	84.67	11.17	95.84	0.11	56.42
Pendimethalin 0.50 kg/ha + imazethapyr 0.10 kg/ha	99.83	13.50	113.33	0.11	57.38
Weedy check	120.83	17.17	138.00	0.27	0.00
LSD (P=0.05)					7.41

Yield parameters

Data pertaining to yields (Table 2) revealed that, treatment pre-emergence application of oxyflourfen 0.10 kg/ha followed by post-emergence application of imazethapyr 0.10 kg/ha immediate after harvest of Ist cut recorded significantly higher yield values of green fodder, dry matter, crude protein, seed and straw (34.39, 4.53, 0.81, 0.47 and 5.87 t/ha, respectively) than rest of the treatments. The selective action of oxyflourfen and imazethapyr was the reason for better control of grassy and broad-leaves weeds resulted in poor crop weed competition during critical crop growth period,which resulted meager competition of weeds to crop in respect to moisture, space, sunlight and nutrition which caused better growth and development of crop. For improving yield quality parameters and broad-spectrum weed control. Stidham and Singh (1991) reported that imidozolinone herbicides inhibit acetolactate syntase which is essential for leucine, valine and isoleucine synthesis. It may be inferred that weed free environment facilitated better growth and crop development with higher berseem green forage and seed yield. These results were similar with the findings of Tamrakar *et al*. (2002), Tiwana *et al*. (2002), Pathan and Kamble (2012) and Pathan *et al.* (2013).

Prajapati *et al.* (2015) found that the green forage (2283.80 q/ha), dry forage (31.93 t/ha) and crude protein yield (7.60 t/ha) was significantly more due to imazethapyr 0.15 kg/ha applied immediately after 1st and 2nd cut but seed yield was significantly more due to oxyflourfen 0.10 kg/ha + imazethapyr 0.15 kg/ha (immediate after 1st cut) *i.e.* 0.67 t/ha compared to remaining herbicidal treatments.

Economics

The economics studies (gross monetary returns, net monetary returns, maize fodder equivalent yield and benefit: cost ratios) are presented

Table 2. Effect of different treatments on yield of berseem crop

Treatment	Yield (t/ha)				
	Green forage	Dry matter	Crude protein	Seed	Straw
Pendimethalin 0.30 kg/ha	23.11	3.07	0.57	0.35	4.73
Pendimethalin 0.40 kg/ha	19.68	2.61	0.49	0.34	4.13
Pendimethalin 0.50 kg/ha	17.44	2.23	0.41	0.32	3.85
Oxyflourfen 0.10 kg/ha	24.56	3.01	0.56	0.39	5.09
Imazethapyr 0.10 kg/ha (immediate after harvest of Ist and IInd cut)	19.64	2.48	0.47	0.36	3.93
Oxyflourfen 0.10 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of Ist cut)	34.39	4.53	0.81	0.47	5.87
Pendimethalin 0.30 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of Ist cut)	28.22	3.87	0.71	0.41	5.22
Pendimethalin 0.40 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of Ist cut)	23.75	3.22	0.59	0.37	4.96
Pendimethalin 0.50 kg/ha + imazethapyr 0.10 kg/ha	21.07	2.66	0.50	0.35	4.38
Weedy check	13.52	1.74	0.31	0.23	3.08
LSD (P=0.05)	2.24	0.29	0.05	0.02	0.53

Table 3. Effect of different treatments on economics of berseem crop

Treatment	Gross monetary returns (x10^3 \`/ha)	Cost of cultivation (x10^3 \`/ha)	Net monetary returns (x10^3 \`/ha)	Maize fodder equivalent yield (t/ha)	Benefit: cost ratio
Pendimethalin 0.30 kg/ha	135.06	42.80	92.26	49.95	3.16
Pendimethalin 0.40 kg/ha	122.45	42.25	80.19	43.42	2.90
Pendimethalin 0.50 kg/ha	111.76	42.47	69.28	37.54	2.63
Oxyflourfen 0.10 kg/ha	146.82	48.49	98.32	53.25	3.03
Imazethapyr 0.10 kg/ha (immediate after harvest of Ist and IInd cut)	124.88	52.19	7.27	39.37	2.40
Oxyflourfen 0.10 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of Ist cut)	189.31	55.26	134.04	72.68	3.43
Pendimethalin 0.30 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of Ist cut)	160.27	49.01	111.26	60.22	3.27
Pendimethalin 0.40 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of Ist cut)	139.90	48.24	91.66	49.65	2.90
Pendimethalin 0.50 kg/ha + imazethapyr 0.10 kg/ha	128.75	47.33	81.42	44.09	2.72
Weedy check	83.71	45.77	37.94	20.57	1.83
LSD (P=0.05)			8.68	4.66	0.18

Selling rate (Rs./q) of berseem for green fodder (275), seed (18500) and straw (127.5) in Table 3. Pre-emergence application of oxyflourfen 0.10 kg/ha followed by post-emergence application of imazethapyr 0.10 kg/ha immediately after harvest of I[st] cut recorded maximum gross monetary returns (` 1,89,313/ha) net monetary returns (` 1,34,048/ha) and B:C ratio (3.43) compared to rest of the treatments. It was followed by pendimethalin 0.3 kg/ha + imazethapyr 0.10 kg/ha (immediate after harvest of I[st] cut) for B:C ratio (3.27). This might be due to reduced crop weed competition during the crop growth period resulting in higher uptake of nutrient and more accumulation of dry matter, thereby increasing monitory returns. The results were in accordance with Pathan and Kamble (2012) and Pathan *et al.* (2013).

It was concluded that the application of oxyflourfen 0.10 kg/ha + imazethapyr 0.10 kg/ha in berseem (var. *Wardan*) recorded highest green fodder, dry matter and crude protein yields to the tune of 34.39, 4.53 and 0.81 t/ha, respectively with net monetary returns of ` 1,34,048/ha, benefit cost ratio of 3.43 and maize fodder equivalent yield of 72.68 t/ha. The same weedicide combination was recorded highest seed yield (0.47 t/ha), straw yield (5.87 t/ha) and weed control efficiency (80.97%) with lowest weed dry matter yield (0.05 t/ha). This treatment was found to be most productive and remunerative.

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Pre- and post-emergent herbicides for control of castor weeds

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ABSTRACT

A field experiment was conducted during 2012 to 2014 to find out most suitable and cost effective weed management practice for rain fed castor on the medium black soils of central dry zone of Karnataka. The experiment consisted of ten treatments involving two pre-emergence herbicides (trifluralin and pendimethalin) alone and in combination with hand weeding / intercultivation, inter-cropping of castor + groundnut (1:3 ratio), three weedings (20, 40 and 60 DAS), farmers' practice (one weeding at 20 DAS *fb* two inter-cultures at 45 and 60 DAS), two post–emergence herbicides (quizalofop-ethyl and fenoxaprop-p-ethyl, both at 0.05 kg/ha at 25 DAS) and weedy check. The pooled results of three seasons revealed that pre-emergence application of pendimethalin at 1.0 kg/ha *fb* one inter-cultivation at 40 DAS resulted in better weed control efficiency and seed yield (1.61 t/ha) and B:C ratio (4.3) comparable to farmers' practice (1.33 t/ha) and three weeding (1.99 t/ha). Herbicides controlled grasses gave moderate yield comparable to farmers' fields. Weedy check reduced the yield by 76% due to severe competition offered by grasses and broad-leaf weeds. The large scale demonstration on five farmers' fields in Chitradurga district also revealed that pendimethalin at 1.0 kg/ha *fb* one inter-cultivation at 40 DAS (1.48 t/ha and 3.90) gave seed yield and B:C ratio comparable to farmers' practice of weed control (1.49 t/ha and 3.70).

Key words: Castor, Economics, Pendimethalin, Trifluralin, Weed control

Castor (*Ricinus communis* L.) is indigenous to the south-eastern Mediterranean Basin, Eastern Africa and India, but is wide spread throughout tropical regions and is widely grown elsewhere as an ornamental plant (Phillips and Rix 1999). Castor is a member of the Euphorbiaceae (spurge) family. Castor has been cultivated for centuries for oil stored in its seeds. Since ancient times, it has been exploited for its oils and fats to serve as important raw material for the manufacture of soaps, paints and varnishes, hair oils, lubricants, textiles, auxiliaries, pharmaceuticals etc. (Copley *et al.* 2005, Morris *et al.* 2011).

Oilseeds in India constitute the principal commercial crop. (Kumar Naik *et al.* 2015). Castor is preferred by the farmers in traditional castor growing states due to increasing demand and remunerative market price. In India during 2012-13, castor occupied an area of 13.17 lakh ha with a production of 21.77 lakh tones and productivity of 1.65 t/ha (Anonymous 2014) and meets about 90% of the world's requirement of castor oil. India is earning about ` 2253 crores of foreign exchange through export of castor oil and its derivatives with high level of demand rising annually at 3-5% annum (Hegde 2010). Weed infestation is one of the constraints limiting the production of castor (Yadav and Singh 2007). Prevalence of high temperature coupled with relative humidity and frequent rainfall favors luxuriant weed growth which smother crop by restricting its growth particularly during early stages by offering severe weed competition for essential resources (Prasad *et al.* 1991). Castor is a species of C_3 photosynthetic metabolism and being a wider spaced crop with slow initial growth and a low ability to compete for resources with other species makes it vulnerable to weed competition (Azevedo *et al.* 2006) and first 40 days appeared to be critical.The conventional method of weed control is very effective, expensive, labour intensive and time consuming and do not allow weeding at rains during the critical period (Singh *et al.* 2013) resulting in poor weed control. According to a study by Azevedo *et al.* (2006), weeds decreased castor yield by 86%.

Option to control grass species are the ACCase (Acetyl-CoA carboxylase (ACC)) inhibitor herbicides applied post-emergence, such as quizalofop-p-ethyl, clethodim, fenoxaprop-p-ethyl, propaquizafop and butroxydim (Macielet *et al.* 2007, 2008, 2012, Silva

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et al. 2012). The possibility of applying post-emergence herbicides can be a strategy to enhance the control of eudicotyledons plants (Sofiatti *et al.* 2012). Information regarding use of herbicides in castor under rain fed conditions is meager and hence, an attempt has been made to work out an effective weed management strategy using herbicides alone or in combination with inter-culture/hand weeding in central dry zone of Karnataka.

MATERIALS AND METHODS

This study was conducted at the Zonal Agricultural and Horticultural Research Station, Hiriyur (13^0 57' 32" N, 70^0 37' 38" E, 606 MSL), University of Agricultural and Horticultural Sciences, Shivamogga, India. The soil of the experimental sites belonged to medium black soil having pH of 7.7, low available nitrogen (162 kg/ha), medium available phosphorus (16.2 kg/ha) and potassium (270 kg/ha). The total rainfall received during 2009, 2010 and 2011 was 745.2, 937.6 and 347.8 mm with 50, 51 and 28 rainy days respectively, during the crop growth period (June - December). The meteorological data during the course of crop growth were obtained from Agro Met Observatory (Gramina Krushi Mausam Sewa), Department of Agronomy, Hiriyur.

Field experiments were conducted for three consecutive years (2009, 2010 and 2011) during the *Kharif* seasons at Zonal Agricultural and Horticultural Research Station, Hiriyur, Karnataka to identify the most suitable integrated weed management option in castor. The experiment consisted of 10 treatments (Table 1) namely two pre-emergence herbicides (trifluralin and pendimethalin) alone and in conjunction with hand weeding/inter-cultivation, inter-cropping of castor + groundnut, weed free plots also maintained for comparison (3 times weeding), two post-emergence herbicides (quizalofop-ethyl and fenoxaprop-p-ethyl) and season-long weed competition (weedy check). The experiment was laid out in a randomized block design with three replications. The previous crop was chickpea in experimental field. The '*DCH- 177'* variety of castor was sown using two castor seeds per hill on ridges by hand dibbling at recommended spacing of 90 cm (between rows) x 60 cm (plant to plant) with a depth of 8-10 cm. Seeds were treated with bavistin 3 g/kg to protect plants from seed borne diseases. Compound fertilizer [NPK (12:32:16)] at a rate of 20 kg nitrogen, 40 kg of phosphorus and 20 kg potassium as basal dose followed by top dressing with an additional 20 kg N/ha each at 35-40 and 65-70 days after sowing applied. Pre-emergence (one day after sowing) and post-emergence herbicides (25 DAS) were applied using spray volume of 600 and 500 l/ha respectively, using knap sack sprayer with flat fan nozzle. At two weeks after sowing, the seedlings of castor crop were thinned to 1 plant per hill. Acephate at the rate of 1.25 kg/ha was applied with a hand operated knapsack sprayer to semi-looper (*Achoea janata* L.) control.

Data on weed density and weed biomass were recorded with the help of a quadrant (0.25 m^2 area) placed randomly at two spots in the plots at 30 DAS and harvest. Weed control efficacy was calculated based on weed density by using the formula suggested by Mani *et al.* (1973). The data on weed density and weed biomass were subject to square root transformation prior to statistical analysis to improve variance homogeneity.

RESULTS AND DISCUSSION

The major weed flora in the experimental fields and on farm validation sites consisted of *Digitaria ciliaris*, *Dactyloctenium aegyptium*, *Echinochloa colona* and *Chloris barbata* (among grasses); *Cyperus rotundus* (sedge), *Ageratum conyzoides*, *Acanthospermum hispidum* and *Commelina benghalensis* (among broad-leaved weeds).

During all the years, different weed control treatments including herbicidal weed control practices applied either alone or in combination with hand weeding and farmer's practice proved effective in reducing the total weed count and weed dry weight compared to weedy check (Table 1). In weed free treatment, plots were hand weeded thrice at 20 days interval (20, 40 and 60 DAS) and farmers practice (one hand weeding (HW) 25 DAS *fb* two intercultural at 45 and 60 DAS) plot was also an effective means of weeding where weed density and weed biomass was significantly lower than weedy check. However, herbicides sole application of trifluralin or pendimethalin (PE) at 1.0 kg/ha without supplemening of HW and interculture were found less effective in season-long control of weeds compared to integrated treatments and proved to be superior to weedy check. In different weed control treatments, integration of one hand weeding over the application pendimethalin herbicides and farmer's practice at 40 DAS caused significant reductions in the density and fresh biomass of weeds when compared to respective sole application of pre- and post-emergent herbicides.

Improvement in the weed control efficiency to the tune of 18 to 20% was recorded when one hand weeding was super imposed with sole application of pre-emergence herbicides, trifluralin or pendimethalin. The lowest weed density (1.67 g/m^2), minimum weed dry weight (11.67 g/m^2) and the highest weed control efficiency (95.5%) was recorded with pre-emergence application of pendimethalin 1.0 kg/ha *fb* hand weeding at 40 DAS (Table 1). The present results were in agreement with the findings of earlier study which indicated that integrating one hand weeding at 40 DAS along with pre-emergence application of metolachlor 1.0 kg/ha (Manickam *et al.* 2009) or alachlor at 2.0 kg/ha (Dungarwal *et al.* 2002) significantly increased the yield of *Kharif* castor through better weed control. Further, as observed in the present study Iswar Singh *et al.* (2013) has also reported improvement in the weed control efficiency to the tune of 22 to 23% due to combination of one hand weeding along with fluchloralin (PPI) and pendimethalin (PE). Inter-cropping of castor with groundnut in 1:3 ratio lowered the weed density (by 48%) and weed dry matter (by 80%) as compared to weedy check due to more ground coverage by the crops (18.6 g/m^2 and 53.3 g/m^2 as against 36 g/m^2 and 263 g/m^2 in weedy check). The present findings confirmed the earlier studies made by Iswar Singh *et al.* (2013) with inter cropping of castor and groundnut in 1:4 ratio due to coverage of more surface area and suppressing weed growth.

Application of either quizalofop-ethyl or fenoxaprop-p-ethyl 50 g/ha 25 DAS also lowered the weed density and weed dry matter as compared to weedy check and sole application of trifluralin or pendimethalin (PE) at 1.0 kg/ha. However, the extent of control was not at par with weed free plots in these graminicides, as these herbicides control only grasses, without affecting broad-leaf weeds and sedge.

The variations in weeds' growth resulted variations in growth of crop (plant height and number of branches/plant) which directly influenced yield components (100 - seed weight, number of spikes/ plant, primary spike length and number of capsules/ spike) and ultimately castor yield. Major physiological growth parameters and yield attributing characters for three seasons were studied and pooled analyzed (Table 2). There was significant improvement in yield components like primary spike length, 100 seed weight and number of capsules/spike by 39 cm, 30 g and 45.4 respectively due to pendimethalin application at 1.0 kg/ha *fb* inter culture at 40 DAS as compared to weedy check (24.3 cm, 24.7 g and 24.6 respectively). Pendimethalin at 1.0 kg/ha as pre-emergence *fb* weeding at 40 DAS produced significantly higher seed yield (1.61 t/ha) as compared to weedy check (0.48 t/ha), but comparable to three hand weeding (20, 40 and 60 DAS, 1.99 t/ha). These findings were in line with the reports of Dungarwal *et al.* (2002) who obtained effective weed control with the combination of pre-emergence application of pendimethalin (1.0 kg/ha) *fb* hoeing at 40 DAS in castor.

The treatment receiving weeding thrice (` 43,989 /ha) and pendimethalin at 1.0 kg/ha as pre-emergence *fb* inter- culture at 40 DAS recorded

Table 1. Weed competition index (%), weed control efficiency (%), weed dry weight (g/m^2) and total weed count (no./m^2) at harvest in castor as influenced by integrated weed management practices under rain fed condition (pooled data of 2009, 2010 and 2011-12)

Treatment	Total weed density(no./m^2)		Weed dry weight (g/m^2)*		Weed control efficiency (%) at harvest	Weed index (%)
	30 DAS	At harvest	30 DAS	at harvest		
Trifluralin at 1.0 kg/ha (PE)	4.3 (18.0)	3.7 (13.3)	4.2 (16.6)	8.3 (68.7)	73.9	50.7
Trifluralin at 1.0 kg/ha (PE) *fb* 1 hand weeding 40 DAS	4.3 (18.0)	3.5 (11.0)	3.7 (12.6)	4.5 (19.3)	92.7	39.0
Pendimethalin 30 EC at 1.0 kg/ha (PE)	3.1 (8.5)	3.7 (12.7)	3.5 (12.0)	8.1 (64.7)	75.4	39.2
Pendimethalin 30 EC (1.0 kg/ha (PE) *fb* inter-cultivation at 40 DAS	2.9 (8.0)	1.6 (1.7)	2.7 (6.6)	3.5 (11.7)	95.6	19.2
Intercropping castor + groundnut (1:3)	5.8 (32.6)	4.4 (18.7)	4.6 (21.0)	7.3 (53.3)	67.3	39.5
Farmers practice (1 hand weeding 25 DAS *fb* 2 intercultures at 45 and 60 DAS)	1.0 (0.0)	1.8 (2.3)	1.0 (0.0)	3.2 (10.0)	96.2	33.2
Quizalofop-ethyl at 0.05 kg/ha at 25 DAS	3.9 (14.6)	4.7 (21.0)	5.2 (27.0)	14.2 (201)	23.4	34.9
Fenoxaprop -p-ethyl at 0.05 kg/ha at 25 DAS	4.0 (15.3)	4.9 (23.0)	5.6 (31.0)	13.7 (186)	29.0	27.5
Three weeding (20, 40 and 60 DAS)	1.0 (0.8)	1.0 (0.0)	2.3 (8.0)	1.0 (0.0)	100	0
Weedy check	7.2 (51.3)	6.1 (36.3)	6.3 (38.6)	16.2 (263)	0	76.0
LSD (P=0.05)	0.51	0.61	0.6	0.98		

DAS= Days after sowing, PE= Pre-emergence, *fb* = Followed by, NA= Not analysed, averaged over replications. Figures in parentheses are the means of original values. Data were subjected to square root transformation.

Table 2. Growth, yield attributes and seed yield of castor as influenced by integrated weed management practices under rain fed condition (pooled data of 2009, 2010 and 2011-12)

Treatment	Plant height up to primary raceme (cm)	Number of branches /plant	Number of spikes / plant	Primary spike length (cm)	Number of capsules/ spike	100 seed weight (g)	Seed yield (t/ha)	Gross returns (x10^3 `/ha)	Net returns (x10^3 `/ha)	Benefit : cost ratio
Trifluralin at 1.0 kg/ha (PE)	75.6	4.9	3.7	31.1	34.2	25.0	0.98	30.50	17.42	2.3
Trifluralin at 1.0 kg/ha (PE) *fb* 1 hand weeding 40 DAS	71.7	5.6	3.5	29.7	30.8	28.7	1.22	37.73	24.65	2.9
Pendimethalin 30 EC at 1.0 kg/ha (PE)	72.7	5.6	4.3	28.1	35.7	29.3	1.21	37.57	23.70	2.7
Pendimethalin 30 EC (1.0 kg/ha (PE) *fb* inter-cultivation at 40 DAS	80.1	6.4	4.9	39.0	45.4	30.0	1.61	49.97	36.10	3.6
Intercropping castor + groundnut (1:3)	80.9	4.3	3.2	28.73	35.1	28.0	1.21	37.39	22.53	2.5
Farmers practice (1 hand weeding 25 DAS *fb* 2 intercultures at 45 and 60 DAS)	86.4	5.9	4.6	35.9	42.4	29.3	1.33	41.29	24.94	2.5
Quizalofop-ethyl at 0.05 kg/ha at 25 DAS	74.5	5.5	4.1	32.9	35.5	28.7	1.30	40.27	26.81	3.0
Fenoxaprop -p-ethyl at 0.05 kg/ha at 25 DAS	78.7	6.3	5.1	35.3	36.4	30.0	1.45	44.83	31.81	3.4
Three weeding (20, 40 and 60 DAS)	74.7	7.0	4.7	37.1	42.4	30.0	1.99	61.84	43.99	3.5
Weedy check	67.9	3.8	2.8	24.3	24.6	24.7	0.48	14.82	2.96	1.2
LSD (P=0.05)	NS	NS	NS	8.73	9.5	3.6	0.75			

DAS = Days after sowing, PE= Pre-emergence, Average sale rate of castor bean - Rs 31.0/kg, NA= Not analysed, averaged over replications

Table 3. Marginal returns and marginal cost of castor as influenced by integrated weed management practices under rain fed condition

Treatment	Marginal cost (MC)	Marginal returns (MR)	MR/MC
Trifluralin at 1.0 kg/ha (PE)	1225	15686	12.8
Trifluralin at 1.0 kg/ha (PE) *fb* 1 hand weeding 40 DAS	1225	22909	18.7
Pendimethalin 30 EC at 1.0 kg/ha (PE)	2017	22754	11.3
Pendimethalin 30 EC at1.0 kg/ha (PE) *fb* inter-cultivation at 40 DAS	2017	35154	17.4
Intercropping Castor + groundnut (1:3)	3000	22568	7.5
Farmers practice (1 hand weeding 25 DAS *fb* 2 inter-cultures at 45 and 60 DAS)	4500	26474	5.9
Quizalofop-ethyl at 0.05 g/ha at 25 DAS	1600	25451	15.9
Fenoxaprop -p-ethyl at 0.05 kg/ha 25 DAS	1160	30008	25.9
Three weeding (20, 40 and 60 DAS)	6000	47027	7.8
Weedy check	-	-	-

higher net returns (` 36,099/ha) and with respect to B:C ratio pendimethalin at 1.0 kg/ha as pre-emergence *fb* inter- culture at 40 DAS recorded higher (3.6) than other treatments. As observed in the present study, Iswar Singh *et al*. (2013) also observed similar net returns (` 74,464/ha) and B:C ratio (1.3:1) by use of pendimethalin (1.0 kg/ha) *fb* inter-culture over weedy check.

The marginal returns (MR) and marginal cost (MC) of castor were also worked-out to assess the increase in net returns due to different weed management practices. Marginal cost in herbicide treated plots was considerably less (` 1160/ha in fenoxaprop-p-ethyl treatment ` 2017 /ha in pendimethalin) as compared to three hand-weeding costing ` 6000/ha and farmer's practice ` 4500/ha. The higher marginal returns /marginal-cost ratio was obtained in the plot treated with fenoxaprop-p-ethyl, followed by trifluralin and pendimethalin; while it was quite low with farmer's practice and three handweeding owing to herbicides management being cheaper than hand weeding and farmer's practice (Table 3).

Validation through large scale demonstration

The best treatment of pre-emergence pendimethalin at 1.0 kg/ha *fb* inter-culture at 40 DAS was compared with farmers' practice (one hand weeding at 20 DAS *fb* two intercultures at 40 and 60 DAS) on five farmers fields of village Kasturi Rangavanahalli (plot size of one ha) in Chitradurga district during 2013-14 as farm trials through

Table 4. Seed yield and B:C ratio of castor as influenced by integrated weed management practices at farmer's fields in Hiriyur taluk, Chitradurga district (mean of five sites, season: 2012-13)

Treatment	Seed yield (t/ha)	Benefit :cost ratio
Pendimethalin 30 EC (1.0 kg/ha) *fb* inter-cultivation at 40 DAS	1.48	3.9
Farmer's practice (one hand weeding 25 DAS + two inter-culture at 45 and 60 DAS)	1.49	3.7

Note: Averaged over 5 locations; Village: Kasturi Rangavanahalli

farmers' participatory approach. The large scale demonstration revealed that farmers practice (one hand weeding 25 DAS + 2 interculture at 45 and 60 DAS) gave seed yield (1493 kg/ha) comparable to that of pre-emergence pendimethalin at 1.0 kg/ha *fb* one inter cultivation at 40 DAS (1477 kg/ha), besides similar benefit: cost ratio (3.70 and 3.90, respectively).

It was concluded from the study that pre emergence application of pendimethalin (1.0 kg/ha) followed by inter -cultivation at 40 DAS resulted in better weed control to realize higher seed yield and economic returns under rain fed conditions of Hiriyur.

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Weed density assessment with crop establishment in forage crops

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ABSTRACT

Biodiversity is a key to achieve sustainable agriculture. The use of forage crop can promote biodiversity in small holder farming. This study analyzed the establishment of three forage crops (berseem clover (*Trifolium alexandrinum* L.), ryegrass (*Lolium multiflorum* Lam.) and oat (*Avena sativa* L.) with the aim to introduce them into the farmer's crop system. Their competitive ability against weeds was also evaluated. Establishment rate was 33, 40.8 and 97% for berseem, ryegrass and oat, respectively. The low establishment for berseem and ryegrass may be attributed to inadequate sowing period characterized by high temperature and low soil humidity. This is in addition to the allelopathic effect of previous crop for berseem. There was a statistically significant interaction between forage crops and sampling dates on weed density ($p < 0.000$). Berseem was able to suppress weed more than other crops with the lowest weed densities in three sampling dates (56.7, 37.3 and 23.7 plants/m^2). Berseem clover was more competitive due to its leaf area and plant architecture as a leguminous plant. Furthermore, its ability to fix atmospheric nitrogen permits to suffer less than ryegrass and oat in deficiency of fertilizer. At third sampling date, ryegrass was able to restrain weed density with an intermediate developed canopy. It did not differ significantly from weed density in berseem. Oat crop was the most weed invaded along the season. Weeds represented 43.2% and 47.8% in second and third sampling date, respectively. Poor soil, fertilizer absence and lack of moisture influenced negatively oat growth causing this invasion. A negative Pearson correlation ($p<0.001$) between crop biomass and weed density was assessed in berseem and oat indicating that weed competition was translated into a decrease of these crop biomass. Crop management created a more favorable environment for the success of these forage crops in the small holders crop system.

Key words: Competitiveness, Crop establishment, Crop management, Forage, Weed density

Agricultural system based on monoculture to optimize the productivity are widely criticized today (Malézieux *et al.* 2009). A more sustainable, socially just, and secure global food system may be created based on agroecological principles (Kremen *et al.* 2012).The successful introduction of sustainable agriculture into small holder farming system requires discontinuing unsustainable aspects of the current agricultural system specially by practicing diversified crop rotations (Wall 2007). Diversified farming system includes functional biodiversity at multiple spatial and/or temporal scales, through practices developed via traditional and/or agroecological scientific knowledge. Farmers manage this functional biodiversity to generate critical ecosystem services to agriculture (Zhang *et al.* 2007). This may provide critical inputs to agriculture, such as soil fertility, pest and disease control, water use efficiency, and pollination (Kremen *et al.* 2012).

However, Mediterranean climate areas are characterized by their high climatic variability and long drought periods during the growing season, make alternative crop choice difficult and influence competitive effects of weeds (Izquierdo *et al.* 2003).The use of forage crops is an option of income to farmers in between harvests and it permit, with other crops, to diversify the farm production (Pin *et al.* 2011). Forage crops studied in this paper are berseem clover (*Trifolium alexandrinum* L.), Italian ryegrass (*Lolium multiflorum* Lam.) and oat (*Avena sativa* L.). Berseem clover has been an important legume forage crop in semi-arid and arid areas of the world for many years (Day and Taher 1984). It contributes to soil fertility and improves soil physical characteristics (Graves *et al.* 1996) and its forage is superior to grasses in protein and mineral contents (Laghari *et al.* 2000). In Tunisia, it is traditional winter forage on small irrigated farms. Some small farmers cultivate berseem for its seed availability, its high yield and its advantage in crop rotations because it is a good precursor for cereals (Kayouli 2000). Ryegrasse is grown increasingly in rotations with potatoes and other crops to maintain a soil's content of organic matter, to improve its structure, and to reduce erosion. Ryegrass helps to alleviate problems

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associated with intensified row-crop farming and shorter rotation periods (Kunelius and Boswall 2003). Regarding oat, it is a significant crop worldwide, used in animal feed as well as human food (Rivera-Reyes *et al.* 2009).

The biodiversity of arable fields can be divided into planned and associated biodiversity (Vandermeer *et al.* 2002). Planned biodiversity refers to the diversity directly manipulated by a farmer, for instance, the crops chosen for planting. Associated biodiversity consists of the organisms that have colonized the field and thrive there, depending on the way the planned biodiversity is managed. Weed species, *i.e.* all non-cropped plant species encountered in the field, constitute an important part of the associated biodiversity of arable fields.Few studies have focused on the crop/weed interaction process. If advice is to be generated for farmers on how to achieve a competitive crop, the likely variability in crop/weed relationship should be known (Izquierdo *et al.* 2003).

Weeds often form a major problem in weak competitive crops, particularly in low input systems.The relationship between forage crops and weeds in small holder fields is poorly understood. The density of crop plants and weeds is among the various factors that influence the crop-weed balance in a field. It plays a major role in the outcome of competition between them (Altieri 1983). Further, the most accurate method of quantifying the importance of species in the weed vegetation is to count the number of plants/shoots or to measure the biomass per species (Hald 1999). The current study focused on studying the establishment of three forage crops (berseem clover, ryegrass and oat) and evaluating their competitive ability against weeds from October 2013 to April 2014 in order to be introduced into the crop system of the region.

MATERIALS AND METHODS

Vegetation sampling was conducted in three neighboring plots in the experimental field of the higher Institute of Agronomy at Chott Meriem-Tunisia (Latitude: 35.919897; Longitude: 10.565203 (in decimal degrees)). Berseem clover '*Khadhraoui*' and Italian ryegrass '*Thibar*' were sown at the rate of 20 kg/ha on 10th October 2013 instead of recommended rates of 25-30 and 30-40 kg/ha, respectively . Oat '*Meliane*' was sown at the recommended rate (100 kg/ha) on 1st November 2013. All were certified seeds.

All the three forage crops were seeded by manual broadcast onto the soil surface.Cultural operations consisted of a deep ploughing in June 2013 after previous crop harvest was done. Crops did not receive fertilizers or chemical treatments.

Vegetation samplings were carried out in a plot of 90 m^2 (15 × 5 m) in the middle of each field. Vegetation density assessment was recorded separately for crop and weeds by 0.25 m^2 quadrants. There were five sampling dates for vegetation density assessment. It was 7, 10, 18, 23 and 28 weeks after sowing for berseem and ryegrass and 4, 7, 15, 20 and 25 WAS for Oat. Biomass measurements were taken at 7, 23 and 28 weeks after sowing (WAS) for berseem and ryegrass and 4, 20 and 25 WAS for Oat. Six samples using 0.5 m^2 quadrants were taken at randomly from each crop plots. The weed dry matter was assessed by cutting the weeds at ground level, drying them in an oven at 60°C, and recording the final dry weight. The average weed dry biomass per treatment was calculated and expressed in g/m^2.

A two-way ANOVA (in IBM SPSS statistical software, version 20) was conducted to examine the effects of forage crops and sampling dates on weed density. A bivariate correlation was also performed to assess the relationship between crop biomass and weed density; and between total vegetation biomass (crop and weeds) and total vegetation density.

RESULTS AND DISCUSSION

Assessment of forage crop establishment

Mean berseem clover density was 221.3 plants/m^2, (SD=78.6, with an emergence rate of 3% (Fig. 1). The crop was rainfed, so low rainfall in the sowing period (< 1 mm) may affect germination rate. The temperature and rainfall data for the study period, collected from a weather station located near the experimental site, are shown (Fig. 2).

Kayouli (2000) found high sensitivity of berseem clover to soil moisture that can significantly reduces its establishment. It is for this reason that berseem clover is traditionally recommended for irrigated farms in Tunisia. Sub-optimal temperatures (< 25-30°C) after berseem sowing also affected germination (Dalianis 1980). The low germination may also result from high allelopathic effect of barley (Kremer and Ben-Hammouda 2009), which was the previous crop of berseem clover.

Mean Italian ryegrass density was 96.0 plants/m^2 (SD=57.78). The emergence rate was 40.8% which was low due to the fact that it was sown at a period characterized by drought affecting soil moisture, essential for seed germination. According to Kunelius and Boswall (2003), successful

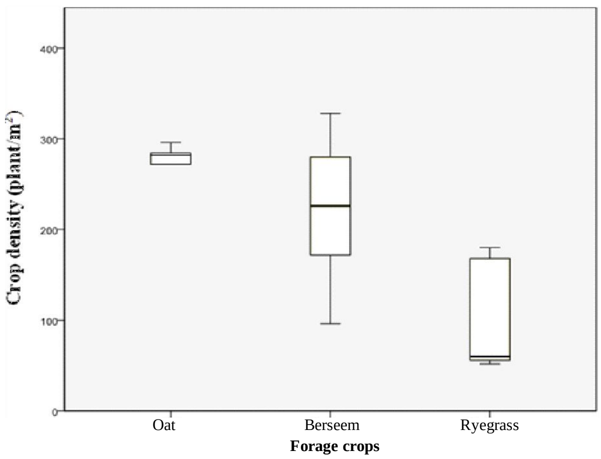

Fig. 1. Establishment of forage crop

(7 WAS Berseem clover and Italian ryegrass and 4 WAS Oat (plants/m^2)

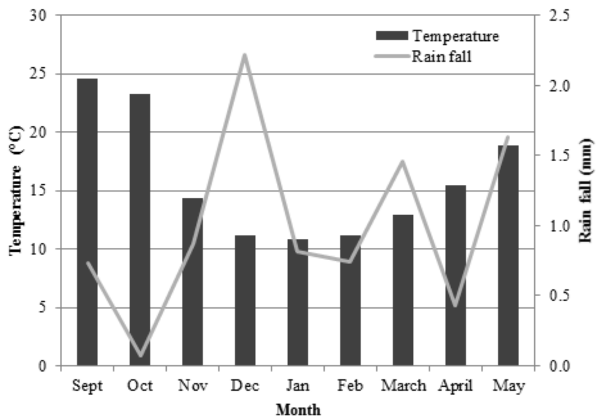

Fig. 2. Monthly mean temperature (°C) and rainfall (mm) from September 2013 to May 2014

establishment of ryegrass may be hampered by lack of moisture after seeding. Further, rapid establishment and homogenous growth can be achieved when ryegrass is sown late in August due to adequate temperature and long photoperiod (Gazwani 2012). Mean oat density was 277.3 plants/m^2, (SD=15.56). The emergence rate at four weeks after oat sowing was about 97%. Oat was sown under a favorable temperature (15°C). Vasilevski (2004) affirmed that optimum oat emergence temperature was 25°C. Sufficient soil moisture due to rainfall, assisted good emergence.

Berseem clover, ryegrass and oat shared the characteristic to be grown under rainfed conditions in areas where the annual rainfall exceeds 450 mm requirements, whereas Chott Meriem is characterized by an annual rainfall of 300 mm (Benzarti 2003). So, local irrigation was needed in this case. Irrigation before sowing was also recommended to help homogenous emerging (Gazwani 2012).

The standard deviation of the mean was important for berseem clover and ryegrass indicating high establishment variability among the field. Since sowing was unsuccessful, crop establishment was very heterogeneous. In fact, these two crops were not adapted to the soil moisture variability in rainfed conditions These are cultivated in the humid zones as well as in irrigated areas in Tunisia (Kayouli 2000). The heterogeneity was less pronounced in oat. This early age success was due to its easy establishment even on badly prepared fields (Kayouli 2000). This characteristic makes it a crop well rooted in the tradition of Tunisian small holders.

Effect of forage crop and sampling dates on weed density

There was a statistically significant interaction between forage crops and sampling dates on total weed density ($p < 0.000$). Therefore, an analysis of simple main effects for sampling dates was performed. All pairwise comparisons were run for each simple main effect with reported 95% confidence intervals and *p*-values Bonferroni-adjusted within each simple main effect (Table 1).

At the first sampling date, berseem clover was in elongation stem stage seven weeks after sowing. It was able to suppress weed more than crops with the lower weed density (56.7 plants/m^2, SD= 20.24), corresponding to 20% of total vegetation (Fig. 3). Oat and ryegrass were, statistically, more weedy. Weed density represented, 29% and 55% of total vegetation in oat and reygrass, respectively. Ryegrass at seven weeks after sowing was tillering. This low establishment might be the cause of its weed infestation. At equal crop densities, berseem clover suppressed weeds better than oat. Berseem clover was ahead of the oat that was at first leaves development stage. Plants were small and weak. Furthermore, the variability in morphological and physiological traits between the berseem clover as a leguminous and the oat as a cereal influences their competitiveness against weeds. Den Hollander *et al.* (2007) indicated that leaf area and plant architecture are considered important characteristics determining the competitive ability of species.

Three weeks later corresponding to second sampling date, berseem clover at 10 WAS reached the stage of axillary shoot formation. These plants were strong enough to continue suppressing weeds more than other crop. Weed density was 37.3 plants/m^2 (SD= 11.29) representing 22.1% of total vegetation. Its quick germination and growth enhanced the berseem competitiveness against weed. For this property, Clark (2007) suggested its sowing as a nurse crop during establishment of other crops such

Table 1. Pairewise comparisons evaluating forage crop and sampling date effects

Sampling date (WAS**)	Forage crop (I)	Forage crop (J)	Difference of means (I-J)	Sig.[b]	Confidence interval of 95%[b] Lower limit	Upper limit
7	Oat	Berseem	56.667*	0.009	11.071	102.262
		Ryegrass	-5.333	1.000	-50.929	40.262
	Berseem	Oat	-56.667*	0.009	-102.262	-11.071
		Ryegrass	-62.000*	0.004	-107.596	-16.404
	Ryegrass	Oat	5.333	1.000	-40.262	50.929
		Berseem	62.000*	0.004	16.404	107.596
10	Oat	Berseem	142.000*	0.000	96.404	187.596
		Ryegrass	39.333	0.115	-6.262	84.929
	Berseem	Oat	-142.000*	0.000	-187.596	-96.404
		Ryegrass	-102.667*	0.000	-148.262	-57.071
	Ryegrass	Oat	-39.333	0.115	-84.929	6.262
		Berseem	102.667*	0.000	57.071	148.262
18	Oat	Berseem	53.333*	0.016	7.738	98.929
		Ryegrass	40.000	0.106	-5.596	85.596
	Berseem	Oat	-53.333*	0.016	-98.929	-7.738
		Ryegrass	-13.333	1.000	-58.929	32.262
	Ryegrass	Oat	-40.000	0.106	-85.596	5.596
		Berseem	13.333	1.000	-32.262	58.929
23	Oat	Berseem	5.333	1.000	-40.262	50.929
		Ryegrass	-4.667	1.000	-50.262	40.929
	Berseem	Oat	-5.333	1.000	-50.929	40.262
		Ryegrass	-10.000	1.000	-55.596	35.596
	Ryegrass	Oat	4.667	1.000	-40.929	50.262
		Berseem	10.000	1.000	-35.596	55.596
30	Oat	Berseem	-13.333	1.000	-58.929	32.262
		Ryegrass	2.333	1.000	-43.262	47.929
	Berseem	Oat	13.333	1.000	-32.262	58.929
		Ryegrass	15.667	1.000	-29.929	61.262
	Ryegrass	Oat	-2.333	1.000	-47.929	43.262
		Berseem	-15.667	1.000	-61.262	29.929

*. The mean difference is significant at .05.
** WAS: (7, 10, 18, 23 and 28) weeks after Berseem and ryegrass sowing, corresponding to 4, 7, 15, 20 and 25 WAS Oat.
b. Adjustment for multiple comparisons: Bonferroni; Standard error= 18.852

as oats, annual ryegrass and alfalfa. Weed density increased in oat and ryegrass up to 179.3 plants/m^2, (SD= 90.96) and 140.00 plants/m^2 (SD= 56.31), respectively. This increase indicated that there was still an empty soil for seedling emergence of new individuals (Tilman 1997). Burke and Grime (1996) have explained that amount of bare ground was consistently the most important factor determining the probability of successful emergence of weeds in grassland systems.

Oat did not succeed to smother weeds that represent about the half (43.21%) of vegetation community. Oat plants, at the stem elongation stage were thin and could not cover the soil to compete with weed. In fact, oat is a relatively demanding plant that should not be installed on poor soils without addition of manure or fertilizer (Husson *et al.* 2012). Nitrogen deficiency symptoms of oat have appeared since the early growth stages and became more severe as the plant grew causing short and thin stems.

At the third sampling date, we noted increase in ryegrass competitiveness due to decrease of weed density by near the half. Ryegrass weed density 37.08 plants/m^2 (SD= 32.44) did not differ from weed density in berseem clover 23.75 (SD= 18.96). It's known that ryegrass is susceptible to nitrogen fertilization which deficiency causes slow growth, however, deficiency needs were met through the previous crop that is sulla (*Hedysarum carnosum* Desf.). Thereby, ryegrass was able to regain partially to develop an intermediate canopy which makes it more competitive than weeds for light, moisture, and nutrients (Isik *et al.* 2009). Berseem clover success was due to its highly efficient water use (Clark, 2007) compared to the other two crops and so it could be adapted to rainfed conditions while ryegrass and oat could not adapted. Oat crop was, most invaded with weeds (53.33 plants/m^2) where weed presented 47.80% of the total vegetation density. It is important to mention that the use of recommended seeding rates in berseem clover and ryegrass, which are higher than the sown doses, helped to smother weed greater.

Crop growth remained relatively slow until the end of the season. We found that ar 28 WAS, berseem clover was at flowering stage. Oat and ryegrass required more than 20 weeks to reach the flag leaf stage. There were no significant differences in weed density between crops for the two last sampling dates. In fact, these two sampling dates coincided with the life-cycle end of weeds explaining decrease of weed density in all crops. New emergences were limited because of the drought season.

Standard deviations of weed density indicated the high variability among the field in most of the observations. In fact, all weed infestations had a patchy (aggregated or clumped) distribution. Weeds were never distributed uniformly throughout field because of variable characteristics of weeds. This heterogeneity can be explained by the sampling error in experimental fields.

Density and biomass relationship

Data on dry crop biomass and on weed density are summarized (Table 2, Fig. 4). Pearson correlation coefficients were -0.692 and -0.664, for berseem clover and oat crop, respectively representing a strong significant ($p< 0.001$) negative correlation between above ground crop biomass (g/m^2) and weed density (plants/m^2). Weed competition was translated directly in decrease of these crops biomass. In fact, Scrosati (2000) reported that plant density was negatively correlated to stand biomass in

Table 2. Pearson correlation between dry crop biomass and weed density

Dry Crop biomass	Weed density		
	Berseem clover	Ryegrass	Oat
Pearson Correlation	-0,692**	-0,119	-0,664**
Sig. (two-tailed)	0,001	0,637	0,003

**The correlation is significant at the 0.01 level (two-tailed)

Table 3. Pearson correlation between dry vegetation biomass and vegetation density

Dry Vegetation biomass	Vegetation density		
	Berseem clover	Ryegrass	Oat
Pearson Correlation	-0,314	0,495*	-0,561*
Sig. (two-tailed)	0,204	0,037	0,015

*The correlation is significant at the 0.01 level (two-tailed)

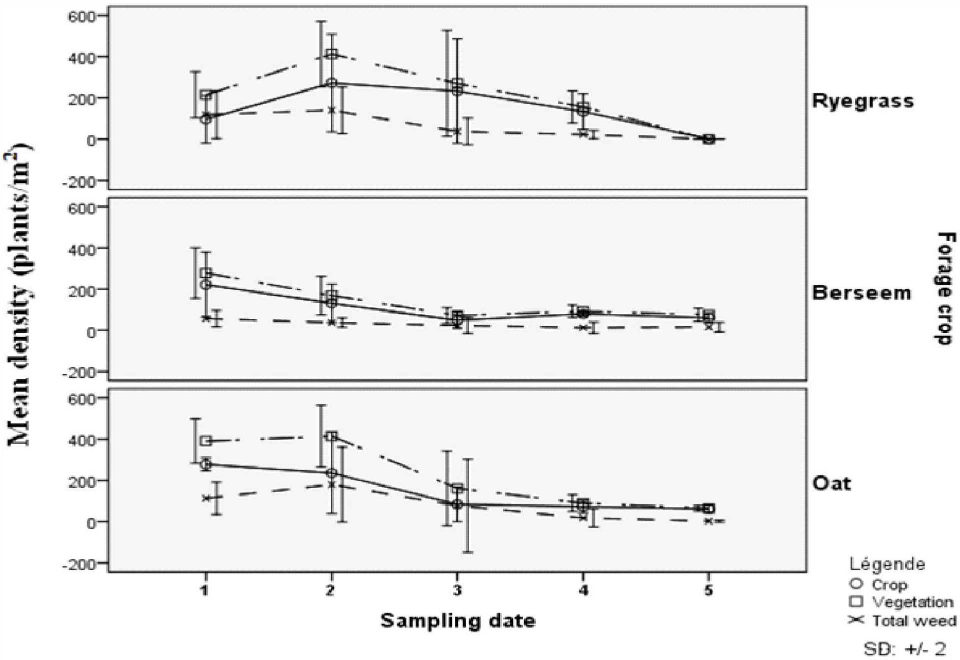

Fig. 3. Evolution of total vegetation, crop and weed densities through sampling dates across the cropping season (plants/m²)

(Sampling dates: 1, 2, 3, 4, and 5 corresponded to 7, 10, 18, 23 and 28 weeks for berseem and ryegrass sowing, respectivelly, and to 4, 7, 15, 20 and 25 WAS for oat)

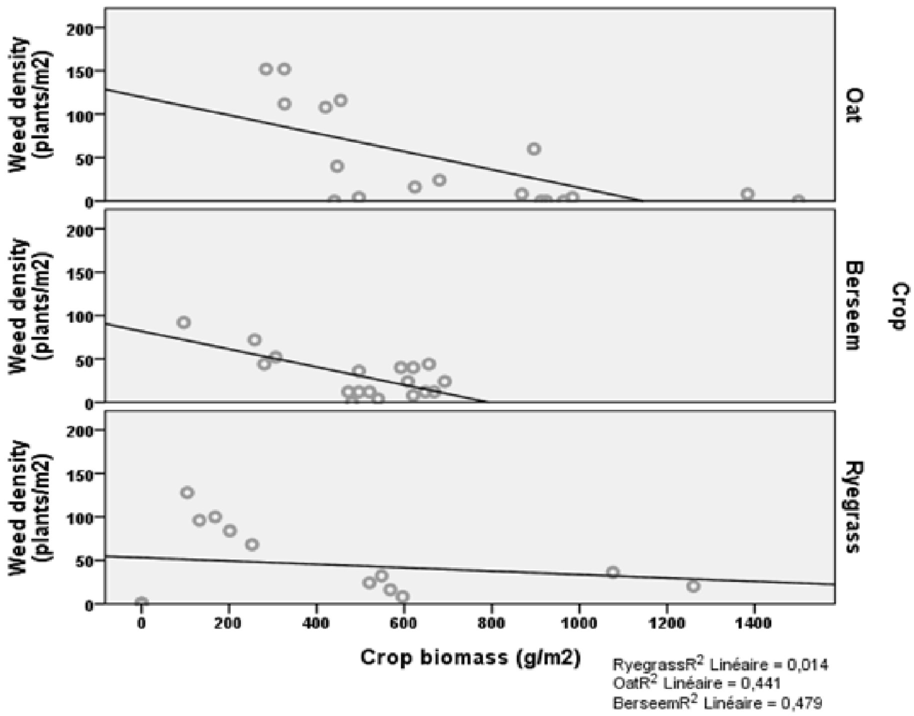

Fig. 4. Relationship between crop biomass (g/m²) and weed density (plants/m²) in oat, berseem and ryegrass crops

case of crowded stands. However, such correlation was not found in ryegrass crop (r=-0.119, *p*= 0.637) suggesting that there were other factors more important in accounting for variability in ryegrass biomass than weed presence. It was suggested that lack of moisture, as crop was carried in rainfed, has a great effect on biomass rate. Moreover, insufficient moisture stoped tiller emergence and reduce significantly ryegrass biomass production compared to irrigated plots (Korte and Chu 1983).

Total vegetation density, composed by both the crop and the weeds, has a negative correlation with total vegetation above ground biomass in oat (r= -0.561, p= 0.015) and a negative trend was not statistically significant in berseem (r= -0.314, p= 0.204) (Table 3, Fig.5). In fact, as density increased, growth of plants becames limited by shortage of environmental supply factors such as light, water and nutrients. Lonsdale (1990) reported that stands of small plants end to accumulate biomass and increase in size until they approach the thinning line. Then, they suffer mortality in a relation to this biomass accumulation (mortality derived from "self-thinning" inside pure stand or from inter-specific competition. In ryegrass case, there was a significant positive correlation (r= +0.495, p= 0.037) between total vegetation density and total vegetation above ground biomass. Density and size of the vegetation community were huge enough to compete and interfere with each other, and increasing density resulted in an increase in vegetation biomass.

Conclusion

This study evaluated the establishment of three crops (berseem clover, Italian ryegrass and oat) and their ability to suppress weeds. It assessed the possibility of their introduction to diversify the cropping system since diversification is a key for sustainable agricultural development. Crop establishment hasn't been very successful, which weakened the competitiveness of crops and allowed weeds to invade the field. If we consider weed density as one of the most important factors in competition (Gherekhloo *et al.* 2010), berseem clover was the most competitive crop against weeds and so less invaded. Italian rye-grass has an intermediate competitive strength. In general, the trajectory of weed density dynamic was decreasing through the season. However, weed competition was strong enough to translate weed density increase into a biomass decrease for both berseem clover and oat.

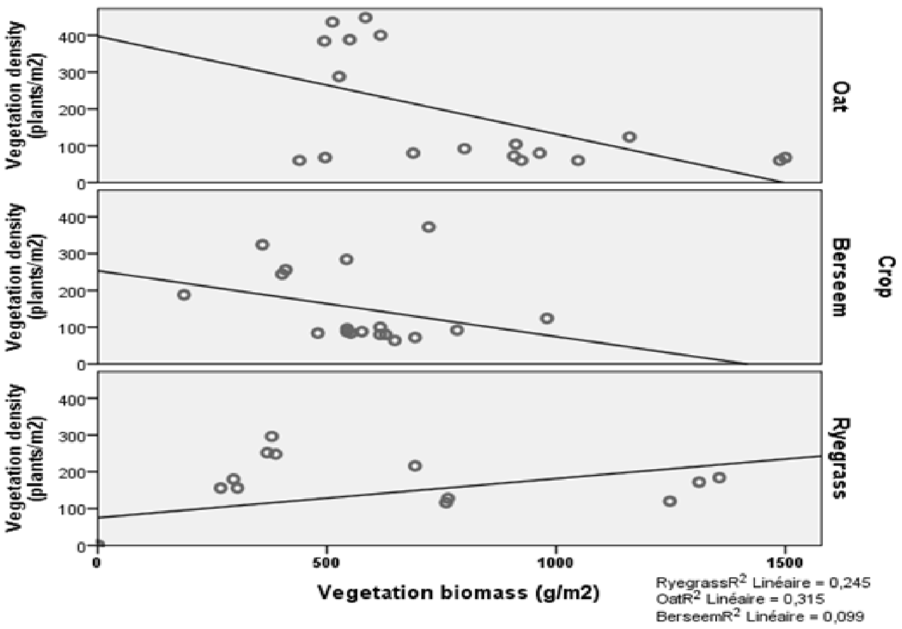

Fig. 5. Relationship between total vegetation biomass (crop and weeds) (g/m^2) and total vegetation density (plants/m^2) in oat, berseem and ryegrass crops

Poor establishment and weed-crop competition were especially influenced by management-related factors, including late sowing, low seeding rate, lack of irrigation and fertilization. Nevertheless, adjusting the crop management enhanced crop competitiveness and aided to suppress weeds. Earlier sowing than those of this experiment offered better conditions for these forage crops. It was reported that berseem clover and rye-grass should be sown better in late August. "*Meliane*" oat cultivar sowing should be done preferably in early October. Irrigation is necessary in the region of Chott Meriem since annual rainfall is less than 450 mm. Fertilizer application is required, especially, in poor soils to enhance crop performance. To reduce fertilizer's charges, it is possible to include forage crops in cropping systems where it can benefit from the back-effects of fertilization made to the main crops (after growing potatoes for example).

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Short communication

Herbicides effect on soil enzyme dynamics in direct-seeded rice

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Key words: Dehydrogenase, Dry seeded rice, Low dose herbicides, Soil enzymes, Urease activity

Dry direct-seeding of rice (DDSR) has emerged as a viable option to combat the rising production costs and shortage of water and labour. Dry sown or semi dry system of rice cultivation is a unique and extensively adopted system of rice cultivation in Kerala and it accounts for more than 60 per cent of the area under rice during *Kharif* season. However, weeds are the most serious biological constraint in dry-seeded rice because of the absence of stagnant water. Use of low dose, high efficiency herbicides is becoming more prevalent which remain more persistent in soil. This necessitates the need to assess the risk of herbicide persistence in soil on soil life. Soil enzyme activity is an indication of microbial activity, which is an integral part of soil environment. Herbicides are extraneous to soil component pools, and are expected to affect the catalytic efficiency and behavior of soil enzymes (Sannino and Gianfreda 2001), which contribute to total biological activity of the soil-plant environment under different situations. Dehydrogenase activity is commonly used as an indicator of biological activity in soils and this enzyme is considered to exist as an integral part of intact cells but does not accumulate extra cellular in soil. Urease enzyme is responsible for the hydrolysis of urea fertilizers applied to the soil into NH_3 and CO_2 with the concomitant rise in soil pH (Andrews *et al.* 1989). This, in turn, results in a rapid N loss to the atmosphere through NH_3 volatilization (Simpson *et al.* 1984). Due to this role, urease activities in soils have received a lot of attention since it was first reported, a process considered vital in the regulation of N supply to plants after urea fertilization.

Various studies have revealed that the herbicides can cause qualitative and quantitative change in enzyme activity (Xia *et al.* 2011). Bensulfuron-methyl, azimsulfuron and pyrazosulfuron-ethyl belongs to sulfonylureas are extensively used to control a wide range of weeds inhibiting acetolactate synthase, a key enzyme in protein synthesis of plants. However, the knowledge about the effect of herbicides on soil enzyme activities in dry sown rice has been limited. In this background, the present study was conducted to find out the effect of these herbicides on soil enzymes *viz*. dehydrogenase and urease for getting a better understanding of the possible response of soil microbial activities to low dose herbicides.

Field experiment was conducted in Vellayani located at 8.5°N latitude and 76.9 °E longitudes at an altitude of 29 m above MSL. A warm, humid, tropical climate is experienced by the experimental area. The soil of the experimental site belonged to textural class of sandy clay which the taxonomical order was oxisol. The soil pH was 5.41 and EC was normal, high in organic carbon, available P and medium in available N and K. Experiment was conducted during *Kharif* season of 2014 by dry direct-seeding in semi-dry system where the field was flooded after 45-50 DAS under randomised block design with three replications. The treatments included different combinations of pre-emergent herbicides with post-emergent herbicide and hand weeding. The new low dose herbicides used were bensulfuron-methyl + pretilachlor, pyrazosulfuron-ethyl (pre-emergent herbicides) and azimsulfuron (post-emergent herbicide) along with a traditional herbicide oxyflourfen applied as pre-emergent herbicide. Pre-emergent herbicides were applied one day after sowing on to the surface of soil using knapsack sprayer with flood jet nozzle while post emergent herbicides were applied at 25 DAS on to the weed flora. The herbicides were sprayed at recommended rates of 660 g/ha for bensulfuron-methyl + pretilachlor as per Sanjay *et al*. (2013), pyrazosulfuron 25 g/ha as per Latha and Gopal (2010) and azimsulfuron 30 g/ha as per Jayadeva *et al.* (2011). The soil samples were taken at a depth of 15 cm before and at 15, 30, 45 and 60 days after sowing (DAS) for determining dehydrogenase. Urease enzyme activity samples were taken at 15 and 30 DAS. Dehydrogenase activity was measured following reduction of 2,3,5-triphenyltetrazolium chloride (TTC) to red-coloured triphenylformazon (TPF), which were determined spectrophoto

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metrically (Casida *et al*. 1964). Urease activity of herbicides treated as well as control soil was determined by titration method described by Broadbent *et al.* (1964).

There was variation in soil enzyme activity in soils as influenced by different herbicide treatments at different period of time. It was observed that dehydrogenase enzyme activity followed an asymptotic behaviour. This pattern could be described by an increase at initial stages reaching a maximum at active tillering stage of the crop followed by a decline towards the harvest stage. At 45 DAS, it showed an increase and after that at 60 DAS, a declining trend was seen. The dehydrogenase activity was significantly higher at 45 DAS compared to other time of plant growth, *viz.* 15, 30 and 60 DAS, which might be due to the spurt in microbial population with the addition of exudates or rhizodeposition during the growth stages *i.e*. up to 45 days. Since dehydrogenase is an endo enzyme, the activity is maximum at the active growth stage of plant (Lu-sheng *et al.* 2005). The highest activity of dehydrogenase recorded at 45 DAS irrespective of the treatment may be due to the fact that it corresponds to the active growth stage of the crop and there is enhanced rhizosphere activity coupled with commencement of flooding from 40 DAS in semi dry rice. These results corroborate the findings of Vandana *et al.* (2012) who reported increase in soil dehydrogenase enzyme activity after herbicide application from 7^{th} to 28^{th} day of incubation which was due to increase in microbial community composition with the capability to utilize herbicide as carbon source.

The data suggested that the detracting effects of soil applied pre-emergent herbicides on soil enzyme activity decreased with time. At 45 DAS, pyrazosulfuron-ethyl 25 g/ha as pre-emergence showed significantly higher activity followed by pyrazosulfuron-ethyl *fb* hand weeding and at 60 DAS, pyrazosulfuron-ethyl with hand weeding recorded the highest activity followed by oxyfluorfen and hand weeding. Among pre-emergent herbicides, oxyflourfen treated plots recorded the highest dehydrogenase activity at 15 days after application when compared to control (weedy check) along with pyrazosulfuron-ethyl. This is contradictory to the findings of Baboo *et al.* (2013) who reported lowest soil dehydrogenase activity in soil treated with the same herbicide under *invitro* situation which might be due to difference in soil biota under field situations. Having the highest dehydrogenase activity at 15 DAS, oxyflourfen could be recommended as a safe herbicide for dry sowing. Hence it could be inferred that herbicides used at recommended rates were non inhibitory on dehydrogenase activity in dry sown situations.

The activity of urease (expressed as urea hydrolysed per gram of soil per hr) as influenced by the herbicide treatments was not inhibited by any of the herbicide treatments. Higher values of urease activity were recorded at both 15 and 30 DAS and higher urease enzyme activity might be attributed to the higher amount of substrate availability during these stages. The urease activity was found to be higher in nutrient applied as well as weedy check plots. This increased urease activity may be attributed

Table 1. Dehydrogenase enzyme activity (TPF/g of soil/ 24 hr) and urease activity (urea hydrolysed/g of soil/hr) as influenced by herbicide treatments

Treatment	Dehydrogenase enzyme activity (TPF /g of soil /24 hr)				Urease activity (Urea hydrolyzed/g^{-}of soil/hr)	
	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS
Bensulfuronm-ethyl + pretilachlor 60 + 600 g/ha	129.6	182.6	205.8	198.7	70.8	74.4
Bensulfuronm-ethyl + pretilachlor 60 + 600 g/ha + hand weeding at 40 DAS	136.2	179.8	354.7	282.3	67.4	60.0
Bensulfuronm-ethyl + pretilachlor 60 + 600 g/ha + azimsulfuron 30 g/ha as (post-emergence)	150.1	234.0	233.0	127.1	66.0	67.2
Pyrazosulfuron-ethyl 25 g/ha as (pre-emergence)	173.0	247.0	567.8	256.6	90.6	64.5
Pyrazosulfuron-ethyl 25 g/ha as (pre-emergence) + hand weeding at 40 DAS	174.1	131.7	540.7	370.2	58.5	77.0
Pyrazosulfuron-ethyl 25 g/ha as (pre-emergence) + azimsulfuron 30 g / ha	180.1	83.5	159.9	242.2	78.3	75.4
Oxyfluorfen 0.15 kg/ha	275.5	155.9	230.4	295.8	71.3	78.6
Oxyfluorfen 0.15 kg/ha + hand weeding at 40 DAS	239.9	123.7	429.0	336.5	72.6	70.4
Oxyfluorfen 0.15 kg/ha + azimsulfuron 30 g /ha	290.9	99.4	236.5	316.1	84.4	62.1
Hand weeding at 20 and 40 DAS	229.6	177.4	326.5	313.3	80.6	50.4
Weedy check	169.0	235.8	410.3	294.9	80.5	83.0
LSD (P=0.05)	5.43	30.5	9.27	9.86	5.72	7.59

to increased soil nutrients used by urease enzyme releasing microorganisms. (Vandana *et al*. 2012). Hence it could be inferred that herbicides either used as pre-emergence or post-emergence remains in the soil and cause alternations in soil enzyme activities with respect to different days after treatments.

SUMMARY

A field experiment was conducted to study the effect of new generation herbicides on soil enzymes, *viz*. dehydrogenase and urease for getting a better understanding of the possible response of soil microbial activities to low dose herbicides in dry sown rice. The treatments included different combinations of pre-emergent herbicides (bensulfuron-methyl + pretilachlor, pyrazosulfuron-ethyl) with post-emergent herbicide (azimsulfuron) and hand weeding along with a traditional herbicide oxyfluorfen. The effect of herbicides on soil enzyme dynamics showed that there was an increase in soil dehydrogenase enzyme activity (expressed in triphenylformazanhydrolysed /g of soil /24 hr) from 15 to 45 DAS after an initial decline. The activity of urease (expressed as urea hydrolysed per gram of soil per hr) as influenced by the herbicide treatments was not inhibited by any of the herbicide treatments. Hence it could be inferred that herbicides either used as pre-emergence or post-emergence remains in the active top soil and cause alternations in soil enzyme activities with respect to different days after treatments. The treated herbicides affected the soil enzyme activity but none of them registered highly negative effect on any of the soil enzyme activity in the present study under dry sowing.

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Short communication

Nitrogen and weed management in direct-seeded aerobic rice

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Key words: Aerobic rice, Nitrogen levels, Upland rice, Weed management

Aerobic rice is a new way of production system in which input-responsive rice varieties are grown in well-drained - non-puddled, soils without ponded water. The main driving force behind aerobic rice is to economize the water use. Aerobic rice offers easier planting, reduced labour, early crop maturity and higher tolerance of water deficit (Balasubramanian and Hill 2002). In aerobic rice, weeds emerge along with the crop. However, weeds being hardy and having profuse root and shoot growth habit, grow faster than rice there by check the growth of rice by severe weed crop competition. Nitrogen is the most limiting nutrient for rice production because of its higher requirement by the rice crops (Singh and Singh 2002). So, nitrogen and weed management are two important management factors limiting the productivity of upland aerobic rice.

A field experiment was conducted during *Kharif* season 2010 at Birsa Agricultural University, Ranchi, Jharkhand. The soil of experimental plot was sandy clay loam in texture, with slightly acidic reaction (pH 6.2), low in organic carbon (4.6 g/kg) and available nitrogen (228 kg/ha), high in available phosphorus (35.3 kg/ha) and medium in available potassium (157.1 kg/ha). The experiment was laid out in split-plot design with three replications. The treatments comprised three nitrogen levels in main plots and seven weed control methods in sub-plots. Nitrogen was applied in the form of urea as per treatment. A basal dose of P_2O_5 and K_2O *i.e.* 40 and 20 kg/ha, respectively were applied through di-ammonium phosphate and muriate of potash. Nitrogen was applied in three equal splits as basal, maximum tillering and panicle initiation stage.

Rice variety '*Naveen*' was grown as the test crop. The herbicides were sprayed uniformly with knapsack sprayer fitted with flat fan nozzle calibrated to deliver 500 l/ha water volume. Species wise weed density (no./m^2) and weed dry matter (g/m^2) were recorded by putting a quadrat (0.25 m^2) at three random spots in each plot at 20, 40, 60, 80 and at maturity. Data on weed density and dry matter of weeds were transformed using square-root transformation $\sqrt{x+0.5}$ before statistical analysis and weed control efficiency was calculated on the basis of weed dry matter.

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Effect on weeds

Echinochloa colona, *Eleusine indica*, *Digitaria sanguinalis*, *Bracharia milliformis*, *Paspalum distichum*, *Ludwigia parviflora*, *Sphellanthus acmella*, *Eclipta alba*, *Commelina benghalensis*, *Cyperus iria*, *Fimbristylis milliaceae*, *Cyperus difformis* and *Kyllinga brevifolia* were dominat weeds. All the weed control treatments significantly reduced the weed density and weed dry matter over weedy check. Among the weed control methods, *Sesbania* (dhaincha) in between rice row + pendimethalin 0.75 kg/ha + 2, 4-D 0.8 kg/ha at 25 DAS recorded significantly lower weed density at all crop growth stages as compared to rest of the weed control methods. Except at 20 and 40 DAS where it remained at par with *Sesbania* in between rice row + pendimethalin PE 0.75 kg/ha and weed free check. However, *Sesbania* in between rice row + pendimethalin PE 0.75 kg/ha + 2, 4-D 0.8 kg/ha at 25 DAS being at par with *Sesbania* in between rice row + pendimethalin PE 0.75 kg/ha registered significantly reduced dry matter accumulation to the tune of 19.2, 48.6, 39.6, 38.7 and 73.5%, respectively compared to mean weed dry matter recorded by rest of the weed control methods at 40, 60, 80 DAS and at crop maturity period. Our finding was in accordance with those of Ray and Mishra (1999).

Application of 75 kg N/ha recorded significantly lower weed density and dry matter at all crop growth stages as compared to 100 and 125 kg N/ha. Except at 60 and 80 days after sowing, dry matter was similar to application of 100 kg N/ha. The reduction in total weed density at 20, 40, 60, 80 DAS and at maturity were 14.31, 18.67, 10.84, 12.53 and 16.91, respectively as compared to mean weed density recorded with 100 and 125 kg N/ha. The result was in close conformity with those of Sharma and Ghosh (2002) and Yadav (2004). All weed control treatments resulted in significantly higher rice grain yield than

Table 1. Weed dynamics in aerobic rice as influenced by nitrogen levels and weed management practices

Treatment	Weed density (no./m^2) Days after sowing					Weed dry matter (g/m^2) Days after sowing					Weed control efficiency	Grain yield (t/ha)
	20	40	60	80	At maturity	20	40	60	80	At maturity		
Nitrogen levels (kg/ha)												
N_1- 75	21.3 (464)	23.8 (590)	28.2 (818)	30.6 (967)	26.9 (744)	14.2 (205)	21.4 (477)	27.2 (756)	28.7 (850)	26.3 (709)	49.2	3.53
N_2- 100	22.9 (527)	26.2 (704)	29.4 (885)	31.9 (1055)	29.1 (870)	15.2 (233)	23.1 (548)	27.5 (773)	29.1 (872)	27.3 (769)	44.9	3.74
N_3- 125	23.5 (556)	27.0 (747)	30.4 (950)	33.4 (1156)	29.9 (921)	15.6 (246)	23.6 (568)	27.8 (790)	29.4 (883)	28.9 (851)	39.1	3.90
LSD (P=0.05)	0.82	0.87	0.59	0.55	0.61	0.54	1.26	0.38	0.80	0.97	-	1.11
Weed management practices												
Dhaincha in between rice row + pendimethalin PE 0.75 kg/ha	20.0 (400)	21.8 (476)	25.5 (650)	26.0 (680)	25.0 (627)	13.3 (177)	18.9 (361)	23.7 (565)	25.1 (633)	24.1 (584)	58.2	4.30
Rice + pendimethalin PE 0.75 kg/ha	22.8 (526)	29.2 (856)	31.2 (970)	34.1 (1170)	29.4 (867)	15.2 (233)	25.7 (662)	30.2 (911)	31.7 (1006)	28.3 (803)	42.4	3.42
Dhaincha in between rice row + pendimethalin PE 0.75 kg/ha + 2, 4 D 0.8 kg/ha at 25 DAS	21.1 (446)	20.9 (442)	23.3 (543)	24.6 (607)	23.8 (567)	14.0 (197)	17.6 (313)	22.8 (522)	24.4 (594)	23.2 (539)	61.4	4.37
Urdbean in between rice row + pendimethalin PE 0.75 kg/ha	22.3 (501)	28.4 (808)	30.2 (913)	33.2 (1107)	27.8 (777)	14.9 (222)	24.3 (589)	27.5 (758)	27.7 (770)	26.8 (721)	48.3	3.73
Urdbean in between rice row + pendimethalin PE 0.75 kg/ha+2, 4 D 0.8 kg/ha at 25 DAS	21.7 (475)	25.9 (672)	27.5 (757)	30.1 (910)	26.9 (730)	14.5 (210)	23.5 (555)	26.4 (700)	27.0 (730)	26.2 (690)	50.6	3.78
Weed free check	25.4 (647)	21.2 (458)	28.8 (833)	31.0 (967)	28.5 (817)	16.9 (286)	19.8 (396)	27.8 (774)	28.6 (817)	26.5 (702)	49.6	3.94
Unweeded check	24.7 (613)	32.3 (1048)	38.9 (1517)	44.4 (1975)	39.0 (1532)	16.5 (271)	29.0 (841)	34.3 (1180)	39.0 (1525)	37.3 (1396)	-	2.53
LSD (P=0.05)	1.19	0.86	0.87	1.01	1.21	0.79	1.42	1.23	1.40	1.35	-	2.98

Figures in parentheses are original values and were transformed to $\sqrt{x} + 0.5$ before statistical analysis

weedy check. Rice crop growth and yield contributing characters were affected adversely due to weedy condition, which resulted in 90% loss of rice grain yield. The rice grain yield produced with *Sesbania* in between rice row + pendimethalin 0.75 kg/ha +2, 4-D 0.8 kg/ha at 25 DAS) followed by *Sesbania* in between rice row + pendimethalin 0.75 kg/ha proved their superiority over rest of the weed management practices. These findings were in conformity with Angadi and Umapathy (1997).

SUMMARY

Application of 125 kg N/ha and in a planting *Sesbania* in between rice row + pendimethalin PE 0.75 kg/ha + 2, 4-D at 0.8 kg/ha at 25 days after sowing found to be best option for both growth and yield of rice.

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Short communication

Booster for mitigating the effect of ALS inhibiting herbicides on rice yield

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Key words: Rice, ALS inhibiting herbicides, Mitigating treatments, Yield and yield attributes

Weed control is a major cultural operation in rice cultivation. Weeds emerge simultaneously with crop seedlings and grow more quickly in moist soil resulting in severe competition for resources (Chauhan 2012), and yield losses may be ranged from 50 to 90%.

ALS inhibitors are a group of post-emergent herbicide which are popularly used by the farmers for weed control in the rice field. Their mode of action is by inhibiting synthesis of branched chain amino acids. As these groups of herbicides affect the protein metabolic pathway, a slight reduction in yield has been noticed by farmers. Studies by Ramanaraya (2014) has shown that the reduction in yield may be due to inhibition of photosynthetic rate, stomatal conductance, reduction in nitrate reductase enzyme activity and IAA content. This necessitates management interventions. Some of the hormones like NAA and micronutrients also have a pivotal role in the overall development of the rice plant. Molybdenum, is a co-factor of the key enzymes of assimilatory nitrogen metabolism in plants. Zinc is an essential element for tryptophan synthesis which is the precursor of IAA (Taiz and Zeiger 2010). Application of boron is helpful in cell growth and further development of plants. These chemicals and their combinations were tried to develop a management technology to improve the physiological efficiency of the rice after the application of the post-emergent ALS inhibiting herbicides.

An experiment using the rice cultivar '*Manupriya*' was conducted during *Kharif* season of 2015 at Agricultural Research Station, Mannuthy in Thrissur district in Kerala. The experimental soil was medium in fertility and having pH 5.0. The experiment was laid out in randomized block design with 11 treatments, replicated thrice.

Before starting the experiment, soil samples were collected from the experimental site and analyzed for basic properties like pH, EC and macro and micro nutrients. The area was ploughed, puddled and levelled. The plot size adopted was 15 m^2 (5 x 3 m). Plots of 5 x 3 m were made by taking bunds of 20 cm width and height. After levelling, fertilizers N:P:K was applied as 70:35:35 kg/ha. Secondary and micronutrients were applied as per soil test data except in treatments T2, T4, T7 and T9, where zinc, boron and molybdenum was given as spray. Urea, factamphos, muriate of potash, borax and magnesium sulphate were used for supplying the nutrients. Full dose of P was applied basally. N, K, B, Mg were applied in two equal splits during land preparation and panicle initiation stages. After basal fertilizer application, the seeds were dibbled at a spacing of 15×10 cm at the rate of 150 g/plot (90 kg/ha). Hand weeding was done at 20 and 40 DAS. Both the herbicides were sprayed at 15 DAS using knapsack sprayer at the recommended doses and all nutrients were sprayed at 35 DAS at the recommended doses.

Micro nutrient spray contained 1gm each of zinc sulphate, borax and 0.01 gm of molybdic acid/litre. NAA was applied 100 ppm. Observation of yield attributes and yield were recorded after harvesting. Results were analyzed statistically.

Maximum number of tillers were observed in tank mix applied plots (330.67) followed by T_2 (bispyribac-sodium *fb* micronutrient spray). All other treatments recorded lesser number of productive tillers/m^2 as compared to other treatments (Table 1). Minimum number of tillers was recorded in the treatments T_{10} (azimsulfuron + water spray at 35 DAS) and T_6 (azimsulfuron + 1% urea spray at 35 DAS) which were at par with each other. Spikelets/panicle varied in different mitigating treatments. The maximum number of spikelets (120.33) were observed in treatment T_4. Treatment T_{10} recorded least number of spikelets (97.67) followed by the treatment T_{11}. The maximum number of filled grains was noticed in treatment T_4 (116.33) followed by the treatment T_2 (109.67) and T_3. High percentage of chaff content was recorded in hand weeded control (9.14) followed by water spray (8.08) in azimsulfuron applied plots. Bispyribac-sodium applied plots recorded higher yield and yield attributes

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Table 1. Effect of mitigating treatments on yield parameters

Treatment	No. of productive tillers/ m^2	No. of spikelets/ panicle	No. of filled grains/panicle	Chaff percentage	1000 grain weight (g)
T_1	316.00^{bc}	109.67 ^{b}	102.33^{cd}	6.81 ^{bcd}	31.17^{bc}
T_2	324.33^{ab}	117.00^{a}	109.67 ^{b}	6.23 ^{cd}	30.90 ^{bcd}
T_3	315.67 ^{c}	110.67 ^{b}	104.33 ^{c}	5.71 ^{d}	31.51^{b}
T_4	330.67 ^{a}	120.33^{a}	116.33 ^{a}	3.35 ^{e}	33.06 ^{a}
T_5	309.67 ^{cde}	104.33^{cd}	97.67 ^{ef}	6.32 ^{cd}	29.81^{ef}
T_6	301.67 ^{ef}	103.00^{d}	95.00 ^{fg}	7.77 ^{abc}	29.67 ^{ef}
T_7	305.33 ^{def}	105.00^{cd}	99.33 ^{de}	5.47 ^{d}	30.08 ^{def}
T_8	305.33 ^{def}	101.33^{de}	93.67 ^{fgh}	7.56 ^{bc}	29.28 ^{fg}
T_9	311.00 ^{cd}	108.00^{bc}	101.33^{cde}	6.33 ^{cd}	30.43 ^{cde}
T_{10}	299.33^{f}	97.67 ^{e}	90.00^{h}	8.08 ^{ab}	28.73^{g}
T_{11}	302.00 ^{ef}	101.00 ^{de}	92.00^{gh}	9.14 ^{a}	29.47^{fg}
LSD (P=0.05)	8.51	4.47	4.00	1.54	0.90

In a coloumn, means followed by common letters do not differ significantly at 5% level by DMRT

compared to azimsulfuron applied plots. Grain yield was higher in combined application of urea, micronutrients and NAA applied plots in both bispyribac-sodium and azimsulfuron applied plots (Table 2). But the straw yield was higher in urea application of both bispyribac-sodium (10.88) and azimsulfuron (12.44) applied plots.

When the grain and straw yield of water sprayed treatments were compared with the hand weeded control, there was a 3% reduction in grain yield in the bispyribac-sodium applied plots while 6% reduction was noticed in the azimsulfuron applied plots. Straw yield showed 5.0 and 0.83% reduction in bispyribac-sodium and azimsulfuron applied plots, respectively compared with hand weeded control. Ramanarayana (2014) had also reported that there was a 5-17% reduction in grain yield and 6-17% reduction in straw yield by the application of ALS inhibiting herbicides. The mitigation treatments, urea, micronutrients and NAA spray improved the yield by 21.5- 9.9% in azimsulfuron and bispyribac-sodium applied plots, respectively over the control. 22% improvement in grain yield was observed when treatment T_4 of the bispyribac-sodium applied plots was compared with T_5 where only water spray was given after bispyribac-sodium application. In case of azimsulfuron, 6% increase in grain yield was obtained when the treatment T_9 was compared with T_{10} (water spray).

The effect of Zn application on yield components of rice has been reported by Brown *et al.* (1993), Zn has higher effect on yield rather than vegetative growth. Boron has been identified as an element that increases tillering in rice which may be due to its positive influence on photosynthate translocation through vascular bundles of petioles (Ali *et al.* 1996). These might be the factors which have contributed to an increase in the productivity of rice.

Table 2. Effect of mitigating treatments on yield (t/ha)

Treatment	Grain yield	Straw yield
T_1	5.40 ^{b}	10.88 ^{abc}
T_2	5.46 ^{b}	10.33 ^{bc}
T_3	5.44 ^{b}	9.77 ^{c}
T_4	6.22 ^{a}	10.33 ^{bc}
T_5	5.12 ^{c}	9.88 ^{c}
T_6	5.37 ^{b}	12.44 ^{a}
T_7	6.04 ^{a}	10.44 ^{bc}
T_8	5.33 ^{b}	11.77 ^{ab}
T_9	5.60 ^{b}	10.33 ^{bc}
T_{10}	5.28 ^{c}	9.33 ^{abc}
T_{11}	4.97 ^{c}	10.77 ^{c}
LSD(P=0.05)	0.312	1.67

In a coloumn, means followed by common letters do not differ significantly at 5% level by DMRT

Study showed that the initial growth suppression due to application of post- emergent ALS inhibiting herbicides can be overcome with mitigation treatments given on the 35th day and among the treatments combined application of Urea, NAA and micronutrients gave the best results.

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Short communication

Seeding method and weed competition effect on growth and yield of direct-seeded rice under puddled condition

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Rice is the most important staple food crop of India. It is grown as transplanted crop in most of the command areas. But, labour shortage at the peak of planting activities has encouraged many rice farmers to shift from transplanting to direct-seeding in irrigated areas. Direct-seeded rice are subjected to greater weed pressure than conventional transplanting systems since there is no standing water to suppress weeds at the time of crop emergence (Mahajan and Chauhan 2013). The crop is likely to experience yield reduction, unless weeds are kept free during a part of its growing period (Azmi *et al.* 2007). However, use of suitable seeding methods for rapid establishment of rice seedlings (Tilahun *et al.* 2013) may counter weed competition under direct-seeded condition. Hitherto, such studies are meager which evaluate the effect of critical period of weed interference in direct-seeded rice with different seeding methods under puddled condition. Hence, this study was carried out to assess the effect of seeding methods and critical period of weed competition in direct-seeded rice under puddled irrigated condition in coastal ecosystem of Karaikal, Puducherry, Union Territory (UT), India.

A field experiment was conducted under puddled irrigated condition from September, 2014 to January, 2015 at Pandit Jawaharlal Nehru College of Agriculture and Research Institute, Karaikal, (11° 56' N latitude,79° 53' E longitude, 8 m above mean level), Puducherry U.T. The soil of the experimental field was sandy clay loam in texture, near neutral in reaction (pH: 6.94), low in available nitrogen (119 kg/ha) and high in available phosphorus (24 kg/ha) and potassium (366 kg/ha). The experiment was laid out in split plot design with two direct seeding methods and four weed competition periods in five replications. The main plot was allotted with two method of direct-seeding in anaerobic condition *viz*., wet (using pre-germinated seeds) and dry (using non pre-germinated seeds). The sub-plots were assigned with maintaining weedy conditions for early 15, 30, 45 and 60 days after sowing (DAS) of crop growth. The rice cultivar '*ADT 46*' of 135 days duration was sown during September 2014 and harvested during January 2015 with 20 cm spacing between rows. An uniform dose of 150 kg N, 50 kg P_2O_5, 50 kg K_2O and 50 kg Zn was applied in the form of urea, super phosphate, muriate of potash and zinc sulphate, respectively. Half of the N, and full dose of the P_2O_5, K_2O and $ZnSo_4$ was applied as basal and remaining half dose of the nitrogen was applied in two splits: at active tillering and at panicle initiation stage. Weed density (grasses, broad-leaved weeds and sedges) were recorded at 60 days after sowing (DAS) with the help of 50 x 50 cm quadrates at two random places in each plot. The data on weed density and dry weight was transformed using $\sqrt{x + 0.5}$ to normalize their distribution before analysis. The experimental data were subjected to standard statistical analysis.

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Major weeds observed in experimental field were: *Echinochloa crusgalli* L, *Echinochloa colona* L. among grasses, *Cyperus iria* L., *Cyperus difformis* L. among sedges, *Eclipta alba* L., *Marselia quadrifolia* L., and *Bergia capensis* L among broad-leaved weeds.

The weed density and dry weight of grasses, broad-leaved weeds, sedges and total weeds was not significantly influenced by method of direct-seeding under puddled condition but was found to be affected with weed competition periods (Table 1). Weedy condition for initial 15 days of crop growth followed by weed free condition throughout crop growth resulted in lower density of grasses, broad-leaved, sedges and total density of weeds (1.0, 8.3, 2.0 and 11.3 no/m^2, respectively) compared to other periods of weedy condition at 60 DAS. The maximum density of weeds and dry weight was recorded when the weedy condition was maintained upto 60 DAS of crop growth. Further, it was observed that weed floristic composition irrespective of the duration of weedy condition is in the order of broad-leaved weeds > grasses > sedges.

Sowing of either pre-germinated or dry seeds did not influence the growth and yield of rice in puddle condition. Dry seed sowing resulted in less vegetative growth and LAI compared to the pre-germinated seeds. Higher number of productive tillers and filled grains was observed in the sowing of pre-

Table 1. Influence of direct seeding methods and varied weedy condition on weed density and dry weight of rice at 60 DAS

Treatment	Weed density (no./ m^2)				Weed dry weight (g/ m^2)			
	Grasses	Broad-leaved	Sedges	Total	Grasses	Broad-leaved	Sedges	Total
Direct seeding methods								
Wet	2.5(5.8)	5.7(42.3)	1.1(1.3)	6.4(49.5)	2.7(8.9)	3.3(10.4)	0.6(0.1)	4.3(18.6)
Dry	2.8(8.7)	7.2(55.2)	2.8(8.0)	8.3(71.8)	3.4(10.6)	3.8(14.4)	0.9(0.2)	5.1(25.2)
LSD (P= 0.05)	NS	NS	NS	NS	NS	NS	NS	NS
Weedy condition								
Weedy condition up to 15 DAS and then weed free	1.2(1.0)	2.8(8.3)	1.3(2.0)	3.4(11.3)	1.4(1.7)	1.9(2.9)	0.7(0.1)	2.4(4.7)
Weedy condition up to 30 DAS and then weed free	2.3(4.7)	5.7(38.7)	1.8(2.7)	6.5(46.0)	2.5(5.9)	3.1(7.8)	0.8(0.1)	4.0(13.8)
Weedy condition up to 45 DAS and then weed free	2.8(5.7)	8.1(68.0)	1.9(3.0)	8.7(76.7)	3.6(9.8)	3.6(11.0)	0.8(0.1)	4.9(21.0)
Weedy condition up to 60 DAS and then weed free	4.3(17.7)	9.2(80.0)	2.8(11.0)	10.7(109)	4.9(20.0)	5.7(28.0)	0.9(0.2)	7.4(48.2)
LSD (P= 0.05)	1.72	4.15	NS	3.67	1.55	1.47	NS	1.51

Data subjected to $\sqrt{x + 0.5}$ transformation. Figures in parentheses are original values. *DAS- Days after sowing

Table 2. Influence of direct seeding methods and varied weedy condition on growth, yield components and yield of rice

Treatment	No. of leaves	Productive tillers per m^2	Panicle weight (g)	Filled grains/ panicle	Grain yield (t/ha)
Direct seeding methods					
Wet	43.7	374.8	4.2	1284	4.44
Dry	41.7	359.8	3.7	1238	4.01
LSD (P= 0.05)	NS	NS	NS	NS	NS
Weedy condition					
Weedy condition up to 15 DAS and then weed free	46.1	399.0	4.4	1436	4.98
Weedy condition up to 30 DAS and then weed free	44.1	384.2	4.4	1300	4.61
Weedy condition up to 45 DAS and then weed free	43.1	362.0	3.8	1204	4.23
Weedy condition up to 60 DAS and then weed free	37.2	324.0	3.21	1104	3.08
LSD (P= 0.05)	4.54	51.0	0.42	160	0.36

DAS- Days after sowing, NA- Statistically not analyzed

germination sprouted seeds. The result was in conformity with the findings of Tilahun *et al.* (2013). However, weed free condition maintained throughout the crop period except the initial 15 DAS resulted in highest rice grain yield of 4.98 t/ha. It was followed by the weedy condition maintained for early 30 and 45 days of crop growth (4.61 and 4.23 t/ ha, respectively). Similar result was also obtained by Mukherjee *et al.* (2008) in wet-seeded rice under *Terai* (lowland region in southern Nepal and north-western India) conditions. Productivity of rice depends on interaction of various physiological and biological functions in plants. Increased weed competition period reduced the number of leaves productive tillers, panicle weight and filled grains per panicle as that of grain yield (Hakim *et al.* 2013). Significantly lower grain yield (3.08 t/ha) was recorded in the experimental plots maintained weedy for initial 60 days of crop growth (Table 2).

SUMMARY

A field experiment was conducted for direct-seeded rice under puddled irrigated condition in *samba* season (September, 2014 to January, 2015) at Karaikal, Puducherry Union Territory to study the influence of two direct seeding methods (wet and dry sowing) and four periods of weed competition (weedy condition for early 15, 30, 45 and 60 days of crop growth) in split plot design. Weed density and dry weight was not significantly influenced either by sowing with wet or dry seeds but significantly influenced by weed competition. Maximum grain yield, lower weed density and dry weight were recorded with the plots maintained weed free throughout the crop period except the initial 15 days after sowing (DAS).

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Short communication

Herbicide combinations for broad spectrum weed control in wheat

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Weed is one of the major biotic constraints in wheat production as they compete with crop for nutrients, moisture, light and space (Chhokar *et al.* 2012). They possess many growth characteristics and adaptations which enable them to successfully exploit the numerous ecological niches. Weeds suppress the crop and result in reduction of yield. Weed control cost is a major segment of input cost in crop production and herbicides provide a better opportunity to control weeds in close row crops like wheat where manual or mechanical weeding is not possible (Yaduraju and Mishra 2002). Apart from an ineffective control measure against mimicry weeds like *Phalaris minor* and *Avena ludoviciana*, manual weeding also involves high cost (Chhokar *et al.* 2012). The present situation of labour shortage and increase in wages has only worsened the situation. Under such situations, herbicides are far cheaper and more readily available recourse than labor for hand weeding. When there is complex weed flora, infestation in wheat crop, the efficacy achieved by one herbicide belonging to single group is limited because of narrow spectrum of weed control. In such situations, mix or sequential application of herbicides with different selectivity can widen the range of weed control, save time, application cost and reduce impact of herbicides on environment, resulting in biological activity higher than their individual applications (Sharma *et al*. 2015). Herbicide efficacy can be increased by tank mixing or ready-mix (RM) formulations, if compatible or by their sequential application for effective control of weed flora in wheat. Compatibility of herbicides depends on mixture partners (Yadav *et al.* 2009). Recent investigations have vouched the importance of herbicide combinations in enhancing wheat productivity through wide spectrum weed.

An experiment was carried out at Agronomy Farm, Maharana Pratap University of Agriculture and Technology, Udaipur during *Rabi* season (winter) of 2015-2016. Soil of the experimental site was clay loam in texture and alkaline in reaction (pH-8.2). The experiment consisted of thirteen treatments (pendimethalin at 750 g/ha, sulfosulfuron at 25 g/ha, metribuzin at 210 g/ha, clodinafop at 60 g/ha, pendimethalin *fb* sulfosulfuron 1000 g + 18 g/ha, pendimethalin + metribuzin 1000 g + 175 g/ha, sulfosulfuron + metsulfuron at 30 g + 2 g/ha (RM), pinoxaden + metsulfuron 60 g + 4 g/ha, mesosulfuron + iodosulfuron at 12 g + 2.4 g/ha (RM), clodinafop + metsulfuron at 60 g+ 4 g/ha (RM), one hand weeding at 30 DAS; two hand weedings at 30 and 45 DAS, weedy check) were tested in a randomized block design in three replications. Wheat variety '*Raj.-4037*' was sown at 22.5 cm row distance using 100 k g/ha seed rate. The crop was supplied with 120 kg N/ha, half of which was drilled in crop rows at sowing while remaining half was top dressed in two equal splits at the time of first and second irrigation. The individual weed species were counted at 45, 60 DAS and harvest. This was done by placing 0.25 m^2 quadrate at two randomly selected spots in each plot, averaged and finally weed count was expressed as number/m^2. Separate counts were recorded for major broad-leaf weeds and grassy weeds. The count data were subjected to square root transformation $\sqrt{X+0.5}$ to normalize their distribution. After recording counts these samples were first sun dried and then oven dried at 70° C till constant weight was achieved. The final dry weight of broad-leaf and grassy weeds was recorded and expressed in kg/ha. The NPK uptake by weeds was estimated at harvest by multiplying the respective contents with weed dry matter. In case of crop, the NPK uptake by grain and straw were estimated by multiplying content with their respective yield. The two were then added to derive total NPK uptake by wheat crop.

Highest number of weeds at 45 DAS was recorded under weedy check. Among herbicide treatments, pendimethalin + metribuzin, metribuzin alone and pendimethalin *fb* sulfosulfuron resulted in

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perceptible reduction in total weed density at this stage. Their results were at par but significantly superior over other treatments, while at 60 DAS, minimum density of total weed was recorded under the effect of sulfosulfuron + metsulfuron (9.99/m^2). Mesosulfuron + iodosulfuron (14.00/m^2), clodinafop + metsulfuron (16.99/m^2) trailed behind it significantly. Compared to weedy check, reduction (57.8 to 96.3%) in total weed density at harvest was observed by exercising various options. Though the hand weeding treatments accounted minimum density of total weeds but good control of weed was registered by sulfosulfuron + metsulfuron followed by mesosulfuron + iodosulfuron, clodinafop + metsulfuron, pinoxaden + metsulfuron and pendimethalin *fb* sulfosulfuron. The data explicitly indicated that weed control through sulfosulfuron + metsulfuron herbicide mixtures gave highest weed control efficiency (79.3, 80.9 and 87.9%) at 45 DAS, 60 DAS and at harvest, respectively (Table 1).

Wide ranging decline in total weed dry matter at 45 DAS were noticed by applying various weed control treatments relative to a weedy wheat crop (Table 1). All the herbicide mixtures and sequential application were significantly superior over alone applied herbicides in reducing dry matter. Sulfosulfuron + metsulfuron brought about 79.9% reduction in dry matter. However, it was at par with pendimethalin *fb* sulfosulfuron and pendimethalin + metribuzin. Significant reduction in total weed dry matter at 60 DAS observed by applying various weed control options under study against weedy check. The trend of significance indicated that sulfosulfuron + metsulfuron with 80.9% reduction in dry matter stood first in the order in significance and outplayed all the other treatments. At harvest, least weed dry matter was observed under sulfosulfuron + metsulfuron (19.22 g/m^2) followed by mesosulfuron + iodosulfuron (22.53 g/m^2).

Marked increase in grain yield of wheat was recorded by weed control, though magnitude of yield differed with treatments. Minimum yield was recorded by one hand weeding which was at par to two hand weedings but inferior to all herbicidal weed control treatments. Two hand weedings was also surmounted by herbicidal weed control except metribuzin. Collective application of herbicides either as pre-mix, tank mix or sequentially resulted in significantly higher grain yield of wheat over singly applied herbicides. Highest yield (6.02 t/ha) was obtained by controlling weeds through sulfosulfuron + metsulfuron followed by mesosulfuron + iodosulfuron (5.80 t/ha). These two treatments recorded 67.6 and 61.3% yield enhancement over weedy check and were at par to each other. The third treatment in the order of merit was clodinafop + metsulfuron which brought 54.6% increase and it was at par with mesosulfuron + iodosulfuron. Application of of pinoxaden + metsulfuron, pendimethalin + metribuzin and sequential application of pendimethalin *fb* sulfosulfuron were next in the order of significance (Table 2).

In contrast to weedy check, all the weed control treatments exhibited significant increase of varying extent in nutrient uptake by wheat crop. The maximum nitrogen (164.62 kg/ha), phosphorus (35.46 kg/ha) and potassium (127.1 kg/ha) uptake were registered by applying sulfosulfuron + mesulfuron, as means for control complex weed flora in wheat crop, (Table 2).

Table 1. Effect of treatments on weed density and weed dry matter

Treatment	Weed density* (no./m^2)			Weed dry matter (g/m^2)		
	45 DAS	60 DAS	At harvest	45 DAS	60 DAS	At harvest
Pendimethalin (750 g/ha)**	5.30 (27.7)	6.23 (38.3)	6.51 (42.0)	36.80	71.61	79.73
Sulfosulfuron (25 g/ha)	7.31(53.0)	4.91 (23.7)	5.01 (24.7)	27.82	55.76	49.85
Metribuzin (210 g/ha)	4.25 (17.7)	5.84 (33.7)	6.09 (36.7)	36.28	73.01	77.77
Clodinafop (60 g/ha)	8.55 (72.7)	5.42 (29.0)	5.72 (32.3)	28.67	57.11	59.23
Pendimethalin *fb* sulfosulfuron (1000+18 g/ha)	4.21 (17.3)	4.72 (22.0)	4.62 (21.0)	20.31	44.41	45.27
Pendimethalin + metribuzin (1000+175 g/ha)	4.05 (16.0)	5.51 (30.0)	5.66 (31.7)	20.82	50.63	52.08
Sulfosulfuron + metsulfuron (RM) (30+2 g/ha)	7.03 (49.0)	3.22 (10.0)	2.78 (7.3)	18.82	28.75	19.22
Pinoxaden + metsulfuron (60+4 g/ha)	7.77 (60.0)	4.83 (23.0)	4.41 (19.0)	25.45	36.76	28.11
Mesosulfuron + iodosulfuron (RM) (12+2.4 g/ha)	7.38 (53.7)	3.80 (14.0)	3.32 (10.7)	21.20	33.12	22.53
Clodinafop + metsulfuron (RM) (60+4 g/ha)	7.62 (57.7)	4.18 (17.0)	3.91 (15.0)	23.36	35.05	25.29
One hand weeding (30 DAS)	7.37 (52.3)	8.97 (80.0)	9.13 (83.0)	39.88	80.56	96.93
Two hand weedings (30 and 45 DAS)	7.37 (52.3)	8.27 (68.0)	8.61 (73.7)	39.88	71.56	80.84
Weedy check	10.18 (103.3)	13.34 (177.7)	14.04 (196.7)	91.60	150.89	160.9
LSD (P=0.05)	0.53	0.48	0.44	2.33	3.70	3.65

Figures in parentheses are original weed count with transformed values at $\sqrt{x+0.5}$; **Through Stomp Xtra 38.7 % CS; RM= Ready mix

Table 2. Effect of treatments on grain yield and nutrient uptake by weeds and crop

Treatment	Grain yield (t/ha)	Net returns (x10^3 `/ha)	Nutrient uptake (kg/ha) By weeds N	P	K	By crop N	P	K
Pendimethalin (750 g/ha)**	4.71	60.65	1.40	0.35	2.31	127.3	25.6	104.6
Sulfosulfuron (25 g/ha)	4.84	63.72	0.97	0.28	1.65	131.9	26.8	106.8
Metribuzin (210 g/ha)	4.50	57.03	1.26	0.33	2.48	121.9	24.6	104.4
Clodinafop (60 g/ha)	4.74	61.55	0.98	0.37	2.56	129.7	27.2	109.2
Pendimethalin *fb* sulfosulfuron (1000+18 g/ha)	5.28	72.17	0.39	0.27	1.30	142.8	30.4	117.9
Pendimethalin + metribuzin (1000+175 g/ha)	5.33	72.64	0.60	0.28	1.48	143.6	30.4	117.2
Sulfosulfuron + metsulfuron (RM) (30+2 g/ha)	6.02	85.57	0.20	0.16	0.42	164.6	35.5	127.1
Pinoxaden + metsulfuron (60+4 g/ha)	5.40	74.25	0.56	0.26	0.78	146.1	31.5	120.8
Mesosulfuron + iodosulfuron (RM) (12+2.4 g/ha)	5.80	81.26	0.23	0.21	0.46	160.2	33.3	123.8
Clodinafop + metsulfuron (RM) (60+4 g/ha)	5.56	76.94	0.26	0.23	0.63	151.5	32.3	123.0
One hand weeding (30 DAS)	4.07	49.01	4.45	1.37	4.18	106.9	22.2	94.1
Two hand weedings (30 and 45 DAS)	4.29	5369	3.58	0.43	2.26	116.0	24.7	101.3
Weedy check	3.59	39.44	6.04	2.06	5.97	92.6	19.3	81.6
LSD (P=0.05)	0.34	6.38	0.04	0.13	0.03	2.45	0.56	2.13

**Through Stomp Xtra 38.7 % CS

Highest NPK uptake was recorded under weedy check but the weed control treatments tended to reduce it significantly. Least uptake was exhibited by sulfosulfuron + metsulfuron, which was followed by mesosulfuron + iodosulfuron but the two were at par, (Table 2). It was significantly superior over rest of the weed control treatments. Similar results on inverse relationship between NPK uptake by weeds and crop under the influence of weed control and concomitant yield enhancement of wheat crop have been documented by Singh *et al.* (2012).

Economical viability of treatments in term of net returns indicated that sulfosulfuron + metsulfuron (RM) and mesosulfuron + iodosulfuron (RM) were the lead herbicide mixtures; which accounted for net returns worth of ` 85566 and ` 81265, respectively. These two treatments gave at par results which significantly surpassed others.

SUMMARY

Field trial was conducted during *Rabi* 2015-2016 at Udaipur to find out an appropriate herbicidal recommendation to augment wheat productivity. The experiment consisted of thirteen treatments (pendimethalin 750 g/ha, sulfosulfuron 25 g/ha, metribuzin 210 g/ha, clodinafop 60 g/ha, pendimethalin *fb* sulfosulfuron at 1000 + 18 g/ha, pendimethalin + metribuzin at 1000 + 175 g/ha, sulfosulfuron + metsulfuron 30 + 2 g/ha, pinoxaden + metsulfuron 60+4 g/ha, mesosulfuron + iodosulfuron at 12 + 2.4 g/ha, clodinafop + metsulfuron at 60 + 4 g/ha, one hand weeding at 30 DAS, two hand weedings at 30 and 45 DAS, weedy check) were tested in a randomized block design in three replications. The results revealed that the mixed population of weeds comprising broad-leaf and grassy was significantly controlled by applying the herbicide mixtures than their alone applications. The sulfosulfuron + metsulfuron mixture resulted in minimum density and dry matter of weeds and NPK uptake by them. The simultaneous increase in NPK uptake by crop by applying this treatment resulted in significantly higher wheat grain yield and nets returns, though the yield and net returns were at par to that of mesosulfuron + iodosulfuron.

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Short communication

Fenoxaprop-p-ethyl effect against weeds in late sown wheat

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Key words: Economics, Fenoxaprop-p-ethyl, Late sown wheat, Nitrogen uptake, Weeds, Yield

Delayed sowing of wheat tends to reduce germination count and number of tillers/unit area because of sharp rise in temperature during tillering phase of the crop and ultimately decrease in yield (Soomro and Oad 2002). Hence, an attempt was made to cultivate weed free late sown wheat by use of fenoxaprop-p-ethyl at different doses in lieu of higher productivity and profitability from rice fallow areas.

Field experiment was conducted during *Rabi* season of 2010-11 at Agronomy Research Farm of N.D. University of Agriculture and Technology, Kumarganj, Faizabad (UP). Ten weed control treatments were consisted in randomized block design with three replications. Soil was slightly alkaline in reaction (7.9 pH), low in organic carbon (0.32%) and low in available nitrogen, phosphorus and medium in potassium. Wheat cultivar '*HUW 234*' was sown on 23rd December with 125 kg/ha of seed at row 20 cm apart at 4-5 cm deep by seed drill. The crop was fertilized with NPK 120- 60-40 kg/ha through urea, single super phosphate and murate of potash, respectively. Out of ten weed control treatments, fenoxaprop-p-ethyl 10 EC was applied at different doses *viz.* 75, 100, 120, 150, 200, 240 g/ha. While market sample of fenoxaprop-p-ethyl 120 g/ha and clodinofop (Topic) were used as standard check Each experiment unit of 5.4 x 5.0 m gross plot size was repeated three times. Treatments were applied as post-emergence at 35 days after sowing (DAS) with the help of knapsack sprayer fitted with flat fan nozzle using 600 liters volume of water. Data on weeds was subjected to square root transformation to normalize their distribution.

Wheat was invaded with *Phalaris minor* (40.2%), *Avena ludovaciana* (14.7%), *Cynodon dactylon* (2.3%) under grassy weeds: *Melilotus alba* (49.9%), *Cheneopodium album* (83.7%), *Anagallis arvensis* (23.8%) under broad-leaved and *Cyperus rotundus* (5.0%) in sedges group. Results revealed that weed density affected significantly due to different weed control treatments. Application of fenoxaprop-p-ethyl at higher doses of 240, 200 and 150 g/ha were equally effective between each other and recorded significantly less density of grassy weeds over rest of the herbicidal treatments. However, lowest and highest density was recorded with weed free and weedy check, respectively. Density of broad-leaved weeds (BLWs) found ineffective among all the test parameters might be due to fenoxaprop-p-ethyl as well as clodinofop were the narrow-leaf weed killer. Similarly, weed dry weight was also significantly lower under these treatments. Application of fenoxaprop at 75, 100, 120 g/ha and clodinofop 60 g/ha were found equally effective on same parameters. Selective bio-efficacy of same herbicides against narrow-leave weeds was also observed by Chhokar *et al.* (2007). Weed control efficiency (WCE) was recorded highest (95.4%) with application of fenoxaprop at higher 240 g/ha rate followed by its lower dose of 200 g/ha (65.2%). However, Whipsuper (fenoxaprop) (standard check) 120 kg/ha found to be significantly more effective in respect to nitrogen removal by weeds and weed index. The phytotoxic effect was also noticed both on crop as well as weeds at higher doses against recommendation of 120 g/ha. Similar findings have also been reported by Jain *et al.* (2007).

The tallest wheat plant (55.5 cm) with significantly increased plant dry weight (389.5 g/m^2) and maximum number of productive tillers recorded with fenoxaprop (Whipsuper) 120 g (370.0/m^2) followed by fenoxaprop 120 g (364.6/m^2), clodinofop (Topic) 60 g and fenoxaprop 100 g/ha, but it did not surpassed the spike count under weed free check (396.5 m^2). However, productive tillers were decreased at each successive increase in doses of fenoxaprop from 150 to 240 g/ha. It might be due to phytotoxic effect of higher dose of fenoxaprop on wheat crop and it has inverse relationship with weed control parameters such as crop growth, yield attributes and grain yield. These results were in conformity with the work done by Malik *et al.* (2005). Herbicides applied at lower doses measured

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Table 1. Effect of weed control treatments on weeds and nitrogen uptake in wheat crop

Treatment	Weed density (no./m^2) at 60 DAS	Weed dry weight (g/m^2) at 60 DAS	Weed control efficiency (%)	Weed index	Nitrogen removal by weeds (kg/ha)
Fenoxaprop-p-ethyl 75 g/ha	13.0 (170)	10.2 (103)	44.0	15.1	3.43
Fenoxaprop 100 g/ha	12.9 (165)	9.9 (97)	56.4	10.7	2.53
Fenoxaprop 120 g/ha	12.8 (164)	9.0 (80)	57.2	7.3	2.10
Fenoxaprop 150 g/ha	12.8 (164)	8.5 (72)	63.1	17.3	3.70
Fenoxaprop 200 g/ha	12.6 (158)	7.8 (60)	65.2	22.5	4.62
Fenoxaprop 240 g/ha	12.7 (162)	7.0 (48)	95.4	23.9	3.31
Fenoxaprop-p-ethyl (whipsuper standard check) 120 g/ha	12.9 (165)	9.2 (84)	59.5	6.5	2.01
Clodinofop (Topic) (standard check) 60 g/ha	12.7 (161)	9.6 (92)	58.7	19.3	2.12
Weedy check	15.5 (240)	11.6 (134)	0.00	33.9	6.54
Weed free	0.7 (0.00	0.7 (0.0)	100.0	0.00	0.00
LSD (P=0.05)	2.50	0.91	-	-	0.56

Data were subjected to square root transformation; values in the parentheses are original values

Table 2. Effect of weed control treatments on crop growth, yield and economics of wheat crop

Treatment	Plant height at 60 DAS	Plant dry weight at 60 DAS (g/m^2)	Productive tiller/m^2	Length of spike (cm)	Grain yield (t/ha)	B: C ratio	Nitrogen removal by crop (kg/ha)
Fenoxaprop-p-ethyl 75 g/ha	51.6	321	320	7.59	3.53	1.85	74.9
Fenoxaprop 100 g/ha	52.3	372	322	7.95	3.72	1.93	77.8
Fenoxaprop 120 g/ha	55.1	387	365	8.88	4.06	2.14	88.0
Fenoxaprop 150 g/ha	48.5	362	219	7.87	3.62	1.76	75.4
Fenoxaprop 200 g/ha	46.7	356	282	7.50	3.39	1.50	69.2
Fenoxaprop 240 g/ha	45.6	313	278	6.75	3.33	1.39	67.3
Fenoxaprop-p-ethyl (whipsuper standard check) 120 g/ha	55.5	389	370	8.91	4.09	2.17	88.4
Clodinofop (Topic) (standard check) 60 g/ha	53.8	385	359	8.81	3.76	2.13	83.7
Weedy check	43.0	277	197	6.11	2.89	1.40	58.1
Weed free	58.0	403	396	9.46	4.38	1.97	95.4
LSD (P=0.05)	6.3	54	54	1.04	0.35	--	6.64

significantly longest spike than higher doses of fenoxaprop at 200 and 240 g/ha. All weed control practices significantly influenced grain yield over the weedy check. Application of fenoxaprop (Whip-super) 120 g, new molecule of fenoxaprop at 100 and 120 g and clodinofop (standard check) 60 g/ha being at par and also recorded statistically higher grain yield over rest of herbicidal treatments. These findings were corroborated with the results obtained by Yadav *et al.* (2009).

SUMMARY

An experiment was conducted during *Rabi* season of 2010-11 at Agronomy Research Farm of NDUAT, Faizabad to assess the influence of fenoxaprop-p-ethyl at various doses with its standard check and clodinofop on weeds, plant growth, nitrogen uptake and production of late sown wheat. All weed control treatments at different doses effectively reduced nitrogen removal by weeds and its ranges in between 2.01 to 4.62 kg/ha. Post-emergence application of fenoxaprop (Whipsuper) standard check 120 g, fenoxaprop-p-ethyl at 100 and 120 g and Topic (clodinofop) 60 g/ha (standard check) produced significantly higher yield under delayed sown wheat.

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Short communication

Comparative performance of different weeding tools in maize

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Key words: Embodied energy, Field efficiency, Winter maize, Weeds, Weeding efficiency

Maize is considered as the third most important food crop among the cereals in India and contributes to nearly 9% of the national food basket and 5% to world's dietary energy supply. In Bihar, maize is grown in all three seasons with an area of 6.98 lakhs ha, producing 21.11 mt with an average productivity of 3.02 t/ha (Annual report 2012-13). The area under *Rabi* maize is gradually increasing in Bihar due to growing market demand by feed and starch industry and increase in minimum support price. Due to wider row spacing, winter maize suffers from severe competition of weeds resulting in 28-100% yield losses (Patel *et al.* 2006). Besides yield losses, weeds also deplete 30-40% of applied nutrients from soil (Mundra *et al.* 2003). The critical period for crop-weed competition in winter maize varies from 15-60 days after sowing (DAS). Thus, it is imperative to eliminate weeds at proper time with appropriate methods. Manual weeding is one of the most important and highly labour intensive farm operations. Mechanical weeding in maize may minimize the loss from 30 to 10% (Shekhar *et al.* 2010). Now, energy efficient manually operated weeders have been introduced for control of weeds in maize (Tajuddin *et al.* 1991), which are cheaper, more efficient, farmers friendly. The present experiment was conducted to evaluate the performance of different weeding tools and the energy embodied for inter-cultural operation in winter maize.

The experimental trial was conducted at ICAR Research Complex for Eastern Region, Patna (25^{o} 35.485 N latitude and 85^{o} 04.951 E longitude) during *Rabi* season of 2015-16 under irrigated ecosystem of Eastern Indo-Gangetic Plan zone. The climate of the experimental site was sub-tropical in nature exhibiting high humidity and medium rainfall. The soil of the experimental plot was clay loam (sand: 23.69%, silt: 39.64% and clay: 37.0%) The maize *'Pioneer hybrid-30R77'* (135 days duration) was sown on 28 December 2015. The crop was dibbled seeded at 18.75 kg/ha at a spacing of 50 × 20 cm. The weed samples *viz.* weed density/m^2 was recorded with using a quadrate of 1×1 m at 45 DAS. The moisture content in soil was recorded at weeding time before using the weeding tools from 0-15 and 15-30 cm soil depth. Mean moisture content of the experimental plot varied from 12.7-17.5%. The monthly mean maximum and minimum temperature during the crop growing period ranged from 22.17 ^{0}C- 32.69 ^{0}C and 8.72 ^{0}C-18.31 ^{0}C, respectively. The experiment was conducted in completely randomized block design with four replications. The weeding implements evaluated were: 'khurpi', (a to small tool for gardening) spade, grubber and wheel hoe. The weeding efficiency, field efficiency and field capacity were measured with standard formula and procedures given as follows:

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Weed control efficiency was calculated by using equation.

$$\text{Weed control efficiency (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where, W_1 = number of weeds before weeding, W_2 = number of weeds after weeding

The field efficiency is the ratio of the effective field capacity to the theoretical field capacity and it is expressed in per cent

$$\text{Field efficiency (\%)} = \frac{\text{effective field capacity}}{\text{theoretical field capacity}} \times 100$$

$$\text{Field capacity} = \frac{W \times S}{10} \times \frac{E}{10}$$

Where, W = theoretical width of cut in meter

S = speed of travel in kilometer per hour, E = field efficiency in percent

Weed flora

The weed flora of the experimental plot was diverse in nature and the major weeds associated with crops were *Chenopodium album*, *Solanum nigrum*, *Rumex dentatatus*, *Cynodon dactylon*, *Cyperus iria* and *Euphorbia hirta*. Crop was mostly affected with broad-leaved weeds (84%) followed by grasses (11%) and sedges (5%). Maximum weed control efficiency was found with 'khurpi' (93.1%) followed by grubber (81.9%), spade (75.5%) and wheel hoe (72.2%) (Table 1). The maximum weeding efficiency with 'khurpi' was because of its capability to work between and within the rows. However, the wheel hoe and grubber cannot be used for removing the weeds within the rows. This might be the reason for lower weeding efficiency of these tools as compared to 'khurpi'. The grubber, wheel hoe and spade has the capacity to till the soil to the desired depth, therefore, it works much better between two rows for weeds control. But spade may cause damage to crop plant, if it is brought nearer to the rows. Because of this limitation of these implement, it gave lower weeding efficiency as compared to 'khurpi'. Similar results were also obtained by Shekhar *et al.* (2010).

Table 1. Effect of weeding tools on weed flora

Weeding tool	Initial weed density (no.)	Final weed density (no.)	Reduction in weed density (no.)	Weed control efficiency (%)
Khurpi	72.11	5.10	67.0	92.9
Grubber	77.20	14.11	63.9	82.8
Spade	74.33	18.13	56.2	75.7
Wheel hoe	70.42	19.12	51.3	72.9

The involvement of man power was also examined with respect to different weeding tools used in controlling the weeds of maize and it was noted that 'khurpi' consumed the maximum man days/ha (36.2) followed by spade (28.3), grubber (13.56) and wheel hoe (10.67). This might be due to more number of man power engaged for making the plot free from weeds in the respective treatment.

The field efficiency (Fig.1) was found maximum for 'khurpi' (84.18%) followed by grubber (81.02) spade (76.47%) and wheel hoe (77.26%). Similar results were found by other author also Shekhar *et al.* (2010). The higher field efficiency of hand tools were because of the minimum time loss such as turning time and other time during operation.

The Field capacity of wheel hoe was found to be 0.008 ha/hr followed by grubber (0.004 ha/hr), Khurpi (0.001 ha/hr) and spade (0.0002 ha/hr), respectively. Garg and Sharma (1998) reported that area coverage with wheel hand hoe in wheat crop was 0.36 ha/day, which was much faster than 'khurpi' 0.064 ha/day. The wide difference in field capacity of different implements is because of the width of soil cutting parts *i.e.* blade of the implement

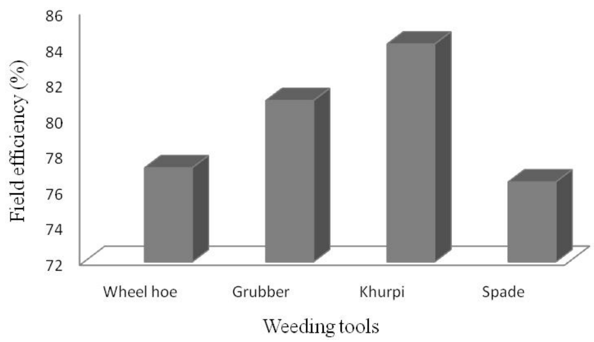

Fig. 1. Field efficiency under different weeding tools

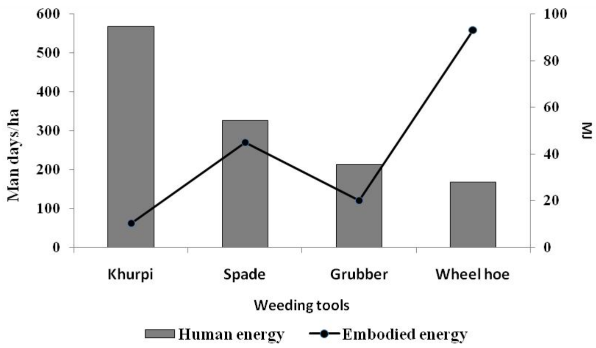

Fig. 2. Human energy *versus* embodied energy

as well as forward speed. Wheel hoe facilitates the worker to provide easy push and pull action to the implement as compare to the grubber. Distribution of embodied energy for different weeding tools in *Rabi* maize is shown in Table 2. It is clearly indicated that the highest embodied energy was found in case of wheel hoe (93.18MJ) followed by spade (45.05 MJ), grubber (20.17 MJ) and 'khurpi' (10.51MJ). The human energy requirement in different weeding tools operation is also shown in Table 3. The highest human energy was consumed by 'khurpi' (567.62 MJ/ha) followed by spade **(**326.62 MJ/ha), grubber **(**212.62 MJ/ha) and hand wheel hoe (167.30 MJ/ha), respectively. Among different weeding tools, wheel hoe had the highest embodied energy and resulting in lowest requirement of human energy. Wheel hoe was not only proved efficient but also useful in completing the weeding in lesser time. It is concluded that human energy can be saved by replacing energy efficient implements.

The human energy (98%) consumed maximum in case of 'khurpi' and the minimum in case of 'wheel hoe' (64%), while, wheel hoe consumed less human energy for using improved implements (Fig. 2).

It may be concluded that in future, the availability of labour for weeding operation will be a great problem due to rapid urbanization and migration of labours. Hence, the weeding tools like grubber and wheel hoe may be promoted for efficient weed control in winter maize.

Table 2. Distribution of embodied energy for different weeding tools in spring maize

Item	Total quantity	Weight (g)	Embodied energy (MJ/kg)	Total embodied energy (MJ)
Khurpi				
Metal plate	01	297.1	27.73	8.24
Plastic handle grip	01	25.2	90	2.27
Total				10.51
Spade				
Metal plate	01	1357	27.73	37.63
Hard wooden Boom	01	390	18.9	7.42
Total				45.05
Grubber				
Furrow -metal	03	715	27.73	19.83
Bamboo rod	01	526.8	0.5	0.26
Screw(1/2")	03	2.7	31.06	0.084
Total				20.17
Hand wheel hoe				
Metal furrow	03	692.6	27.73	19.20
Plastic handle grip	02	100.8	90	9.07
Wheel washer (plastic)	02	13.6	90	1.22
Wheel nut rod	01	70.9	32.0	2.27
Wheel bolt	08	54.1	32.0	1.73
Plastic wheel	01	663.3	90	59.69
Total				93.18

(Anonymous, 2016 and Hetz 1998)

Table 3. Human energy requirement for different weeding tools in spring maize

Items	Human (man-hr/ha)	Energy equivalent (MJ)	Energy requirement (MJ/ha)
Khurpi	289.6	1.96	567.6
Spade	166.6	1.96	326.6
Grubber	108.5	1.96	212.6
Hand wheel hoe	85.4	1.96	167.3

(Ref: Mandal *et al.* 2002 and De *et al.* 2001)

SUMMARY

A field experiment on weeding tools was conducted at farm of ICAR Research Complex for Eastern Region Patna during the *Rabi* season of 2015-16. Results revealed that treatment such as 'khurpi' was recorded the highest weed control efficiency (92.9%) followed by grubber (82.8%), spade (75.5%) and wheel hoe (72.2%). The highest human energy was also attained in case of 'khurpi' (567.62 MJ/ha) followed by spade (326.62 MJ/ha), grubber (212.62 MJ/ha) and wheel hoe (167.30 MJ/ ha). The highest embodied energy was found in wheel hoe (93.18 MJ) followed by spade (45.05 MJ), grubber (20.17 MJ) and 'khurpi' (10.51 MJ). The field capacity of wheel hoe was found maximum (0.008 ha/hr) where as spade was minimum (0.0002 ha/hr). Hence, the wheel hoe was found to be the most efficient and cost effective weeding tool.

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Short communication

Weed management with herbicdes in chickpea

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Key words: Chickpea, Chemical control, Herbicde, Efficacy, Weed management

India is a premier chickpea growing country accounting 76% of total area and production of the world. Yield losses due to weed competition depending on the level of weed infestation and weed species. Yield reduction in chickpea due to presence of weeds to the extent of 75% was noticed by Chaudhary *et al.* (2005). Considerable variations were observed in the application of herbicides by farmers for the control of weeds in chickpea. In view of the above points, the present experiment was planned to evaluate the efficacy of herbicides for weed management in chickpea under middle Gujarat conditions.

The present experiment was conducted in *Rabi s*eason of the year 2012 at the farm of B. A. College of Agriculture, Anand Agricultural University, Anand (Gujarat). The soil was sandy loam in texture having low in available nitrogen and medium in available phosphorus and high in potassium with pH 7.91. Twelve weed management treatments, *viz*. pendimethalin 750 g/ha pre-emergence (PE), pendimethalin 750 g/ha PE *fb* HW at 30 DAS, oxadiargyl 75 g/ha PE, oxadiargyl 75 g/ha PE *fb* HW at 30 DAS, imazethapyr 50 g/ha PE, imazethapyr 50 g/ha PE *fb* HW at 30 DAS, oxyfluorfen 80 g/ha PE, oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS, pendimethalin + imazethapyr (pre-mixed) 750 g/ha PE, pendimethalin + imazethapyr (pre-mixed) 750 g/ ha PE *fb* HW at 30 DAS, interculturing (IC) *fb* hand weeding (HW) at 20 and 40 DAS and weedy check were studied in randomized block design with four replications. The chickpea cv. "*Gujarat Gram-1*' was sown manually keeping the row distance of 30 cm at 60 kg seed/ha during 1st week of November 2012. Entire quantity of nitrogen (20 kg/ha) and phosphorous (40 kg/ha) in the form of urea and single super phosphate, respectively were applied at the time of field preparation. The herbicides were applied using knapsack sprayer fitted with flat fan nozzle as per treatment. The other package of practices was adopted to raise the crop as per the recommendations. Immediately after sowing, a light irrigation was given to the crop for uniform germination and next day the pre-emergence herbicides were applied. The crop was harvested on third week of March 2013. The observations on number of weeds and dry matter of weeds were taken from randomly selected four spots by using 0.25 m^2 quadrate from net plot area. Weed control efficiency (WCE) was calculated on the basis of standard formula as suggested by Maity and Mukherjee (2011). The seed and haulm yield was harvested from the net plot area and converted into hectare for comparison. Data on various observations during the experiment period was statistically analysed as per the standard procedure developed by Cochran and Cox (1957).

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Effect on weeds

At 25 DAS, the lowest suppression of monocot weeds (2.09/m^2) was recorded under oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS (Table 1). Similar results were also observed under weed management practices at 50 DAS with lowest value (3.06/m^2) in oxadiargyl 75 g/ha PE *fb* HW at 30 DAS and IC *fb* HW at 20 and 40 DAS. Dicot weed population (2.87 and 3.23/m^2) was recorded significantly lower under oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS as compared to other treatments at 25 and 30 DAS, respectively. Further, it was observed that oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS recorded significantly lowest dry weight of total weeds (1.35 g/m^2) at 25 DAS. At 50 DAS and at harvest, same trend was noticed except oxadiargyl 75 g/ha PE *fb* HW at 30 DAS, IC *fb* HW at 20 and 40 DAS and imazethapyr 50 g/ha PE *fb* HW at 30 DAS. Oxyfluorfen, oxadiargyl and imazethapyr may persist longer in soil, which restricts the germination of weeds and later germinated weeds can be removed manually at 30 DAS with hand weeding leading to minimum weed population and their dry weight. The result was in close conformity with findings of Poonia and Pithia (2013). Maximum weed control efficiency (83.7%) was achieved under oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS closely followed by oxadiargyl 75 g/ha PE *fb* HW at 30 DAS (83.3%). There was reduction in the yield to the tune of 42.0% under weedy check.

Effect on crop

Plant height at harvest was recorded significantly higher (78.95 cm) under the treatment of oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS as compared to weedy check (63.80 cm). The values of number of yield attributing traits and yields, *viz*. no. of branches/plant, dry weight of *Rhizobium* nodule/ plant and no. of pods/plant, seed and haulm yields were registered significantly higher under oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS than

Table 1. Weed density, dry weight, weed control efficiency and weed index as influenced by different weed management practices

Treatment	Monocot weed count (no./m^2)		Dicot weed count (no./m^2)		Dry weight of total weed (g/m^2)			WCE (%) at harvest	Weed index (%)
	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS	At harvest		
Pendimethalin 750 g/ha PE	3.91^{b} (15.3)	4.90^{b} (24.0)	4.56^{b} (20.8)	7.16^{ab} (51.3)	2.14^{b} (4.6)	10.00^{b} (100.0)	13.46^{b} (181.2)	61.04	35.3
Pendimethalin 750 g/ha PE *fb* HW at 30 DAS	3.80^{b} (14.4)	4.28^{bcd} (18.3)	4.17^{bc} (17.4)	4.64^{cd} (21.5)	2.09^{b} (4.4)	6.87^{c} (47.2)	9.29^{d} (86.3)	67.23	13.5
Oxadiargyl 75 g/ha PE	3.80^{b} (14.4)	4.51^{bcd} (20.3)	4.27^{bc} (18.2)	4.97^{c} (24.7)	2.09^{b} (4.4)	7.50^{c} (56.2)	12.35^{b} (152.5)	68.28	14.7
Oxadiargyl 75 g/ha PE *fb* HW at 30 DAS	2.70^{d} (7.3)	3.66^{de} (13.4)	3.20^{de} (10.2)	3.51^{de} (12.3)	1.58^{e} (2.5)	5.38^{de} (28.9)	6.66^{e} (44.4)	83.31	5.1
Imazethapyr 50 g/ha PE	3.92^{b} (15.4)	4.78^{bc} (22.8)	4.40^{b} (19.4)	6.88^{b} (47.3)	2.11^{b} (4.4)	9.68^{b} (93.7)	12.18^{bc} (148.3)	43.83	23.0
Imazethapyr 50 g/ha PE *fb* HW at 30 DAS	3.06^{cd} (9.4)	3.92^{cd} (15.4)	3.92^{bcd} (15.4)	4.15^{cde} (17.2)	1.80^{cd} (1.2)	6.28^{cd} (39.4)	8.27^{de} (68.4)	74.66	6.7
Oxyfluorfen 80 g/ha PE	3.73^{b} (13.9)	4.39^{bcd} (19.3)	4.14^{bcd} (17.1)	4.68^{c} (21.9)	2.09^{b} (4.4)	7.02^{c} (49.3)	10.13^{cd} (102.6)	40.59	13.8
Oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS	2.09^{e} (4.4)	3.06^{e} (9.4)	2.87^{e} (8.2)	3.23^{e} (10.4)	1.35^{f} (1.8)	4.81^{e} (23.1)	6.66^{e} (44.4)	83.73	0
Pendimethalin + imazethapyr (pre-mixed) 750 g/ha PE	3.66^{bc} (13.4)	4.17^{bcd} (17.4)	4.02^{bcd} (16.2)	4.68^{c} (21.9)	2.01^{bc} (4.0)	6.86^{c} (47.1)	9.34^{d} (87.2)	32.49	13.2
Pendimethalin + imazethapyr (pre-mixed) 750 g/ha PE *fb* HW at 30 DAS	3.52^{bc} (12.4)	4.00^{bcd} (16.0)	4.02^{bcd} (16.2)	4.29^{cde} (18.4)	1.98^{bc} (3.9)	6.79^{cd} (46.1)	8.86^{d} (78.5)	71.21	12.7
IC *fb* HW at 20 and 40 DAS	3.06^{cd} (9.4)	3.78^{de} (14.3)	3.35^{cde} (11.2)	4.11^{cde} (16.9)	1.71^{de} (2.9)	6.17^{cd} (38.1)	8.05^{de} (64.8)	75.54	5.9
Weedy check	5.41^{a} (29.3)	6.80^{a} (46.2)	6.65^{a} (46.2)	8.20^{a} (67.2)	3.00^{a} (9.0)	12.02^{a} (144.5)	16.50^{a} (272.2)	-	42.0
LSD(P=0.05)	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	-	-
C.V.%	11.1	12.3	14.0	13.7	11.9	7.4	12.7	-	-

Original values are in parentheses and before statistical analysis were subjected to square root transformation $(\sqrt{x+1})$

Table 2. Yield attributes of chickpea as influenced by different weed management practices

Treatment	Plant height (cm) at harvest	No. of branch/ plant	Dry weight of *Rhizobium* nodules/plant (g)	No of pods/ plant	Seed index (g)	Harvest index (%)
Pendimethalin 750 g/ha PE	69.6^{bc}	5.5^{d}	49.1^{d}	56.7^{e}	20.9^{abc}	33.2
Pendimethalin 750 g/ha PE *fb* HW at 30 DAS	74.2^{ab}	7.5^{b}	70.5^{b}	80.7^{bc}	21.5^{ab}	36.3
Oxadiargyl 75 g/ha PE	71.4^{abc}	7.2^{bc}	56.4^{cd}	77.0^{cd}	20.8^{abc}	36.8
Oxadiargyl 75 g/ha PE *fb* HW at 30 DAS	76.1^{ab}	8.7^{a}	81.0^{a}	90.0^{ab}	22.0^{ab}	34.0
Imazethapyr 50 g/ha PE	71.0^{abc}	6.2^{cd}	52.0^{cd}	68.2^{d}	20.7^{abc}	36.2
Imazethapyr 50 g/ha PE *fb* HW at 30 DAS	75.1^{ab}	8.0^{ab}	78.8^{ab}	86.2^{abc}	21.8^{ab}	35.0
Oxyfluorfen 80 g/ha PE	72.4^{ab}	7.5^{b}	59.9^{c}	80.0^{bc}	20.3^{bc}	36.2
Oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS	78.9^{a}	8.7^{a}	81.1^{a}	94.5^{a}	22.8^{a}	33.4
Pendimethalin + imazethapyr (pre-mixed) 750 g/ha PE	74.5^{ab}	7.5^{b}	72.3^{ab}	81.2^{bc}	21.8^{ab}	35.4
Pendimethalin + imazethapyr (pre-mixed) 750 g/ha PE *fb* HW at 30 DAS	74.5^{ab}	8.0^{ab}	74.3^{ab}	81.7^{bc}	20.8^{abc}	34.6
IC *fb* HW at 20 & 40 DAS	75.3^{ab}	8.2^{ab}	79.1^{ab}	88.2^{ab}	21.9^{ab}	34.2
Weedy check	63.8^{c}	5.2^{d}	38.3^{e}	56.5^{e}	19.0^{c}	33.6
LSD (P=0.05)	Sig.	Sig.	Sig.	Sig.	Sig.	NS
C.V.%	6.9	9.12	8.6	8.0	6.2	9.97

Table 3. Yields and economics of chickpea as influenced by different weed management practices

Treatment	Seed yield (t/ha)	Haulm yield (t/ha)	Gross returns (x10^3 `/ha)	Total cost of production (x10^3 `/ha)	Net returns (x10^3 `/ha)	BCR
Pendimethalin 750 g/ha PE	1.51	3.03	55.85	23.15	32.70	1.41
Pendimethalin 750 g/ha PE *fb* HW at 30 DAS	2.02	3.54	74.20	24.18	50.02	2.07
Oxadiargyl 75 g/ha PE	1.99	3.41	73.10	23.10	50.00	2.16
Oxadiargyl 75 g/ha PE *fb* HW at 30 DAS	2.21	4.29	81.75	24.13	57.62	2.39
Imazethapyr 50 g/ha PE	1.80	3.16	66.02	22.96	43.06	1.88
Imazethapyr 50 g/ha PE *fb* HW at 30 DAS	2.18	4.04	80.20	23.99	56.21	2.34
Oxyfluorfen 80 g/ha PE	2.01	3.54	73.89	22.64	51.25	2.26
Oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS	2.33	4.63	86.29	23.67	62.62	2.65
Pendimethalin + imazethapyr (pre-mixed) 750 g/ha PE	2.03	3.69	74.60	23.70	50.90	2.15
Pendimethalin + imazethapyr (pre-mixed) 750 g/ha PE *fb* HW at 30 DAS	2.04	3.85	75.15	24.73	50.41	2.04
IC *fb* HW at 20 & 40 DAS	2.19	4.21	81.04	24.01	57.02	2.37
Weedy check	1.35	2.66	49.98	21.18	28.80	1.36
S.Em. $\pm$	0.05	0.27	-	-	-	-
LSD(P=0.05)	Sig.	Sig.	-	-	-	-
C.V.%	0.01	0.015	-	-	-	-

recorded under other treatments except, imazethapyr 50 g/ha PE *fb* HW at 30 DAS, pendimethalin + imazethapyr (pre-mixed) 750 g/ha PE *fb* HW at 30 DAS and IC *fb* HW at 20 and 40 DAS (Table 2). The higher yield attributes and yield of chickpea under imazethapyr herbicide application was also noticed by Goud *et al.* (2013). Significantly, lower seed yield (1.35 t/ha) and haulm yield (2.66 t/ha) was recorded under weedy check but remained at par with pendimethalin 750 g/ha PE for seed and haulm yield and imazethapyr 50 g/ha PE for haulm yield (Table 3). These results were in accordance with the findings of Ratnam *et al.* (2011). The harvest index was unaffected due to various weed management practices in chickpea. Further, it was noticed that application of oxyfluorfen 80 g/ha PE *fb* HW at 30 DAS recorded higher net returns (₹ 63622) with higher benefit cost ratio (2.65) followed by oxadiargyl 75 g/ha PE *fb* HW at 30 DAS, IC *fb* HW at 20 and 40 DAS, imazethapyr 50 g/ha PE *fb* HW at 30 DAS and oxyfluorfen 80 g/ha PE. The lowest BCR ratio (1.36) was observed in weedy check followed by pendimethalin 750 g/ha PE (Table 3).

SUMMARY

Oxyfluorfen 80 g/ha, oxadiargyl 75 g/ha, imazethapyr 50 g/ha as PE *fb* hand weeding at 30 DAS and IC at 20 DAS *fb* hand weeding at 40 DAS were found effective in reducing population of both monocot and dicot weeds and their dry weight as compared to other weed management practices. Higher yield attributing characters and yields were achieved when herbicides, *viz.* oxyfluorfen, oxadiargyl and imazethapyr were applied as pre emergence *fb* hand weeding at 30 DAS.

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Short communication

Integration of pre- and post-emergence herbicides for weed management in pigeonpea

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Pigeonpea is an important pulse crop of India. During 2012-13, it was cultivated in an area of 3.69 million hectares with a production of 2.75 million tonnes and productivity of 753 kg/ha (Indiastat 2014). Pigeonpea is a long duration and widely spaced row crop having slow initial growth rate. The crop canopy does not cover the inter row space during initial phase of growth due to which weeds compete with pigeonpea for available moisture, nutrients and light. The crop suffers from early weed infestation. Therefore, it is necessary to keep the crop weed-free during the early growth period (4-6 weeks). In pigeonpea, weeds cause yield reduction up to 80% (Talnikar *et al.* 2008). Only pre-emergence herbicides are available for weed control in pigeonpea. Among the pre-emergence herbicides, pendimethalin has been found promising in controlling weeds and improving grain yield (Reddy *et al.* 2007, Singh *et al.* 2010a, Singh *et al.* 2010b). However, it is effective only up to about a month and thereafter weeds may pose a problem. Furthermore, weeds emerge in different flushes due to rainy season. Also, one of the important benefits of growing any legume crop is its ability to fix atmospheric nitrogen to plant usable forms, thus, it becomes imperative to assess any possible effects of herbicide application on its symbiotic efficiency. So, there was a need to study the effect of integrated use of pre-emergence and post-emergence herbicides in pigeonpea.

A field experiment was conducted during *Kharif* 2011 at the research farm of Punjab Agricultural University, Ludhiana (30° 56'N, 72° 52'E, altitude 247 m), Punjab. The soil of the experimental site was loamy sand, having pH 8.7, organic carbon 0.29%, available P 11.5 kg/ha and available K 410 kg/ha. Eight treatments (Table 1) were arranged in a randomized block design with three replications. Pendimethalin was sprayed as pre-emergence and paraquat at 6, 8 and 10 weeks after sowing (WAS). These herbicides were sprayed using 375 litre of water per hectare with a knapsack sprayer fitted with a flat fan nozzle. Paraquat was applied between pigeonpea rows as directed spray on weeds only using a plastic hood to avoid any herbicide drift on the crop plants. In the case of two hand weedings, weeds were removed manually with a 'khurpi' (a small tool to remove weeds manually) at 25 and 50 days after sowing (DAS). In unweeded check plots, weeds were allowed during the whole crop growing season.

After pre-sowing irrigation the field was ploughed twice followed by planking at optimum soil moisture. The crop was sown on 14 June 2011. The sowing of variety '*PAU 881*' was done in rows 50 cm apart using a seed rate of 15 kg/ha. The crop was harvested on 28 October, 2011. The crop was raised with recommended package of practices (PAU 2011).

Nodule number was recorded by uprooting five randomly selected plants from each plot at flowering stage. The roots were gently washed and nodule number recorded, the nodules were then carefully detached and dried to constant weight at 60° C in an oven and dry weight recorded. At maturity, data on plant height, branches/plant and pods/plant were recorded from randomly selected five plants from each plot and seeds/pod from randomly selected 20 pods. Biological yield and grain yield was recorded on the basis of whole plot area. From the produce of each plot, 100 seeds were taken for 100-seed weight data. At harvest, weeds from the whole plot were harvested, dried and data converted into t/ha. Weed control efficiency (WCE) at harvest was calculated as per standard formula.

Gross returns, net returns as well as benefit : cost (B:C) ratio were also worked out using prevailing prices of inputs and output. Data were subjected to analysis of variance (ANOVA) in a randomized block design as per the standard procedure.

The predominant weed flora in the field were *Commelina benghalensis* (day flower), *Trianthema portulacastrum* (horse purslane), *Euphorbia hirta*

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(snake weed), *Digitaria* spp. (crab grass), *Dactyloctenium aegyptiacum* (crow foot grass) and *Cyperus rotundus* (nut grass).

Paraquat controlled all weed species whereas pendimethalin controlled all other weed species except *Commelina benghalensis* and *Cyperus rotundus*. Unweeded control plot recorded the highest dry matter of weeds, which was reduced drastically by all other treatments (Table 1). Pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha 6 WAS recorded the lowest dry matter of weeds, followed by pendimethalin 0.45 kg/ha (PE) + hand weeding 50 DAS and pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha 8 WAS. The sole application of pendimethalin as pre-emergence at 0.45 or 0.75 kg/ha was less effective in controlling weeds and improving grain yield, as also reported in earlier studies (Singh and Sekhon 2013). Two hand weedings at 25 and 50 DAS recorded the highest weed control efficiency (86.6%) followed by pendimethalin + paraquat 0.48 kg/ha 6 WAS (85.9%). In pigeonpea, effective weed control has been reported with integrated use of pendimethalin and hand weeding (Rao *et al.* 2003, Shinde *et al.* 2003, Tomar *et al.* 2004, Singh and Sekhon 2013).

Higher nodule number and dry weight was recorded with treatments of integrated use of pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha (8 and 10 WAS), pendimethalin 0.45 kg/ha (PE) + hand weeding 50 DAS, and pendimethalin 0.75 kg/ha (PE). All the treatments significantly enhanced nodule biomass, which is indicative of nodule efficiency. These observations were in accordance with earlier studies (Khanna *et al.* 2012) where no apparent adverse effect of pendimethalin on *Rhizobium* growth was observed under laboratory conditions. Paraquat was found to effect *Rhizobium* growth under in vitro conditions, however, since nodule initiation starts early, so application of paraquat at 8 and 10 WAS, did not hinder nodulation. All the weed control treatments did not affect plant biomass which was more than weedy check, this may be due to effective weed control effected by these treatments.

Integrated use of pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 6 WAS, pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 8 WAS and pendimethalin 0.45 kg/ha (PE) + hand weeding at 50 DAS recorded plant height and branches/plant statistically at par with those in two hand weedings at 25 and 50 DAS (Table 1). Pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 6 WAS and pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 8 WAS recorded significantly higher pods/plant than other treatments except two hand weedings at 25 and 50 DAS. The seeds/pod and 100-seed weight were not influenced significantly by different weed control treatments.

Hand weeding at 25 and 50 DAS recorded the highest biological yield and pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha 6 WAS recorded the highest grain yield (Table 2). The integrated use of pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 6 WAS, pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 8 WAS and pendimethalin 0.45 kg/ha as pre-emergence (PE) + hand weeding at 50 DAS recorded biological yield and grain yield statistically similar to that in two hand weedings at 25 and 50 DAS and pendimethalin 0.75 kg/ha (PE). Higher yield

Table 1. Dry matter of weeds, weed control efficiency, plant characters and yield attributes of pigeonpea as influenced by different weed control treatments

Treatment	Dry matter of weeds (kg/ha)	Weed control efficiency (%)	Number of nodules /plant	Nodule dry weight (mg/plant)	Plant dry weight (g/plant)	Plant height (cm)	Branches/ plant	Pods/ plant	Seeds/ pod	100-seed weight (g)
Pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha (6WAS)	361	85.9	6.8	48.6	9.6	189.9	16.7	201.8	4.1	6.67
Pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha (8WAS)	448	82.6	8.0	54.6	9.8	187.2	15.7	194.7	4.1	6.40
Pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha (10WAS)	1010	60.7	8.0	51.3	9.5	180.9	13.9	163.6	3.9	6.27
Pendimethalin 0.45 kg/ha as pre-emergence (PE)	1429	44.4	7.7	51.3	9.2	187.7	14.0	168.4	4.1	6.50
Pendimethalin 0.45 kg/ha (PE) + HW at 50 DAS	400	84.4	7.8	53.3	9.5	189.0	17.2	184.1	4.1	6.47
Pendimethalin 0.75 kg/ha (PE)	743	71.1	7.5	52.0	10.3	187.5	15.7	185.1	4.1	6.27
Hand weeding at 25 and 50 DAS	343	86.6	8.0	50.6	8.7	191.9	17.7	193.5	4.3	6.80
Weedy check	2571	-	4.2	42.6	8.2	147.7	12.1	145.0	3.9	6.47
LSD (P=0.05)	170		2.2	6.0	NS	5.8	2.6	14.1	NS	NS

Table 2. Yield, harvest index and economics of pigeonpea as influenced by different weed control treatments

Treatment	Biological yield (t/ha)	Grain yield (t/ha)	Harvest index (%)	Gross returns ($x10^3$ Rs/ha)	Net returns ($x10^3$ Rs/ha)	B:C ratio
Pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha (6 WAS)	8.12	1.57	19.38	67.64	51.73	3.25
Pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha (8 WAS)	7.68	1.55	20.14	66.52	50.62	3.18
Pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha (10 WAS)	6.52	1.20	18.40	51.60	35.69	2.24
Pendimethalin 0.45 kg/ha as pre-emergence (PE)	6.67	1.25	18.79	53.88	38.60	2.53
Pendimethalin 0.45 kg/ha (PE) + HW at 50 DAS	8.06	1.49	18.53	64.20	44.29	2.23
Pendimethalin 0.75 kg/ha (PE)	7.25	1.39	19.14	59.64	43.69	2.74
Hand weeding (HW) at 25 and 50 DAS	8.26	1.52	18.40	65.36	41.51	1.74
Weedy check	5.65	0.91	16.05	39.00	24.40	1.67
LSD (P=0.05)	1.06	0.25	-	-	-	-

in these treatments was due to better control of weeds. Similar results were reported by Padmaja *et al.* (2013). In case of pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 10 WAS, the grain yield was quite low. This might be due to result of delayed application of paraquat (10 WAS) as by that time weeds might had adversely affected the growth of the crop.

The maximum harvest index was obtained with the application of pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 8 WAS followed by pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 6 WAS (Table 2). The maximum gross returns (` 67639/ha), net returns (` 51734/ha) and B:C ratio (3.25) were obtained with the integrated use of pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 6 WAS followed by pendimethalin 0.45 kg/ha (PE) + paraquat 0.48 kg/ha at 8 WAS.

SUMMARY

A field experiment was conducted at Punjab Agricultural University, Ludhiana to study the effect of integrated use of pre-emergence herbicide pendimethalin and post-emergence herbicide paraquat on weeds, growth and yield of pigeonpea. Paraquat should be applied between pigeonpea rows as directed spray on weeds only using a plastic hood to avoid any herbicide drift on the crop plants. Pre-emergence application of pendimethalin 0.45 kg/ha followed by paraquat 0.48 kg/ha at 6-8 weeks after sowing effectively controlled the weeds, improved the grain yield of pigeonpea and also provided the high returns. Herbicides did not advesely affect nodule number and nodule dry weight, indicating their safe use under field conditions.

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Short communication

Bio-efficacy of quizalofop-ethyl + imazethapyr in black gram

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Key words: Black gram, Seed yield, Economics, Imazethapyr, Quizalofop-ethyl, Weed control efficiency

Black gram (*Vigna mungo*) is one of the important pulses grown in Tamil Nadu. The area under black gram in the state is around 2.15 lakh ha with a production of 0.71 lakh tons, which accounts for an average productivity of 328 kg/ha. The earlier studies revealed that period from sowing upto 30 days is the critical stage of weed competition and any measure taken to control the weeds in this period will result in additional grain yield. Pre-emergence application of pendimethalin at 2 l/ha at 3 days after sowing (DAS) is commonly recommended to control the weeds (Rathi *et al.* 2004). However, farmers are not following pendimetalin application due to various reasons. As hand weeding is laborious and costly besides non availability of labour for weeding, use of suitable early post-emergence herbicides for weed management in irrigated black gram is the only option available with the farmers. Quizalofop-ethyl, a selective post-emergence herbicide, controls annual and perennial grassy weeds effectively in blackgram (Mundra and Maliwal 2012). Hence, this experiment was proposed to evaluate early post-emergence herbicides, quizalofop-ethyl + imezethapyr on weed control efficiency, productivity and profitability in summer irrigated black gram.

A field experiment was conducted at Tamil Nadu Rice Research Institute, Aduthurai to evaluate the quizalofop-ethyl alone and tank mix with imazethapyr for the control of weeds in irrigated blackgram during Summer season 2012. The soil of the experimental field was alluvial clay with pH of 7.7 and EC of 0.4 dS/m. The experimental soil was low, high and medium in available nitrogen, phosphorus and potassium contents, respectively. The experiment was laid-out in a randomized block design with seven treatment in three replications. The blackgram (*ADT 5*) was sown at 25 kg/ha seed rate in 30 x 10 cm spacing. Herbicides were sprayed at 15 DAS when the weeds were 2-4 leaves stage using flat-fan nozzle as per treatments schedule. Spray volume at 250 l/ha was used. Observations on weed density, weed dry weight and seed yield were recorded. Weed count was recorded by using 0.25 m^2 quadrate at four places in each plot and expressed as number/m^2. Square root transformation ($\sqrt{x+0.5}$) was used to analyze the data on weeds as described by Bartlett (1947).

Weed species like *Corchorus olitorius, Cliome viscose, Trianthema portulacastrum, Eclipta alba, Acalifa indica* in broad-leaved weeds, *Cynodon doctylon, Panicum repens* and *Echinochloa colona* in grasses and *Cyperus rotuntus* in sedges were predominant in the experimental field. Among the weeds, grasses including germinated rice seedlings from shattered paddy seeds (65.2%) were dominant followed by broad-leaved weeds (25.4%) and sedges (9.4%). Effect of early post-emergence herbicides on weed density revealed that all the treatments recorded significantly lesser grassy weeds density in comparison to unweeded check at 10 and 30 DAT. Among treatments, quizalofop-ethyl at 31.25 g/ha + imazethapyr at 62.5 g/ha, weed free check and quizalofop-ethyl at 37.5 and 50 g/ha recorded significantly less grassy weeds in comparison to remaining treatments mainly due to quizalofop-ethyl, which controlled the grasses as it affects the acetyl CoA synthesis in plants (Table 1). These findings were in accordance with Mundra and Maliwal (2012) who reported that spraying of quizalofop-ethyl at 50 g/ha as selective post-emergence herbicide recorded the lowest grasses density and dry weight at 30 DAS and at harvest stages in blackgram. The sedges population was found to be significantly less in quizalofop-ethyl at 31.25 g/ha + imazethapyr at 62.5 g/ha and weed free check in comparison to remaining treatments and both were at par with each other. Minimum weed dry weight of 10.0 and 18.4 g/m^2 at 10 and 30 DAT, respectively obtained in weed free check, closely followed by quizalofop-ethyl at 31.25 g/ha + imazethapyr at 62.5 g/ha and both the treatments were significantly superior over remaining treatments and also were at par with each other. Higher weed control efficiency of 82.7% and 94.2% was recorded at 10 and 30 DAT in weed free check, respectively closely followed by quizalofop-ethyl at

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Table 1. Effect of early post emergence herbicides on the weed density and dry weight at 10 and 30 DAT in black gram

Treatment	Weed density at 10 DAT (no/m^2)			Weed dry wt. (g/m^2) 10 DAT	Weed density at 30 DAT (no/m^2)			Weed dry wt. (g/m^2) 30 DAT
	Grasses	Sedges	BLW		Grasses	Sedges	BLW	
Farmers practice (2 HW on 15 and 30 DAS)	120.0 (11.0)	79.0 (7.98)	25.0 (4.96)	16.67	95.0 (9.77)	28.20 (5.35)	12.0 (3.53)	39.3
Quizalofop-ethyl 37.5 g/ha	8.0 (2.97)	80.0 (8.89)	28.0 (5.33)	17.2	7.0 (2.79)	220.0 (14.8)	30.0 (5.51)	90.1
Quizalofop-ethyl 50.0 g/ha	10.0 (3.27)	85.0 (9.18)	23.3 (4.85)	13.6	6.0 (2.58)	170.0 (13.0)	28.0 (5.35)	85.2
Quizalofop-ethyl + imazethapyr (31.25 + 62.5 g/ha)	9.0 (3.13)	30.0 (5.21)	8.0 (2.97)	11.0	4.0 (2.16)	10.0 (3.26)	12.0 (3.55)	20.4
Quizalofop-ethyl + imazethapyr (15 + 30 g/ha)	110.0 (10.5)	40.0 (6.36)	19.0 (4.61)	44.0	120 (11.0)	45.0 (6.74)	22.0 (4.74)	89.7
Weed free check	22.0 (4.74)	8.0 (2.95)	4.0 (2.20)	10.0	20.0 (4.56)	32.0 (5.66)	8.0 (2.94)	18.4
Unweeded check	632.3 (25.1)	90.0 (9.45)	18.0 (4.32)	55.8	592.0 (24.3)	60.0 (7.63)	20.0 (4.56)	317.4
LSD (P=0.05)	2.08	1.57	1.63	5.97	1.47	2.43	1.78	22.32

DAT: Days after treatment, DAS: Days after sowing, Figures in parentheses are transformed values $\sqrt{x + 0.5}$

Table 2. Weed control efficiency, grain yield and economics of irrigated black gram as influenced by early post emergence herbicides

Treatment	Weed control efficiency (%)		Grain yield (t/ha)	% increase over unweeded check	Net monetary returns (x10^3 `/ha)	Benefit Cost Ratio
	10 DAT	30 DAT				
Farmers practice (2 HW on 15 and 30 DAS)	70.4	87.6	1.01	212.3	26.26	2.9
Quizalfop-ethyl 37.5 g/ha	69.2	71.6	0.73	125.4	18.39	2.7
Quizalofop-ethyl 50.0 g/ha	75.6	73.2	0.82	154.5	21.78	3.0
Quizalofop-ethyl + imazethapyr (31.25 + 62.5 g/ha)	80.3	93.6	0.98	202.8	27.58	3.4
Quizalofop-ethyl + imazethapyr (15 + 30 g/ha)	21.1	71.7	0.79	145.6	21.19	3.0
Unweeded check	-	-	0.32	-	3.82	1.4
Weed free check	82.1	94.2	1.04	223.3	26.16	2.7
LSD (P=0.05)			0.12	-		

DAT: Days after treatment

31.25 g/ha + imazethapyr at 62.5 g/ha (80.3% and 93.6% at 10 and 30 DAT, respectively). The farmer practice (2 hand weeding on 15 and 30 DAS) registered the weed control efficiency of 70.4% and 87.6% at 10 days after first weeding and 15 days after 2nd weeding, respectively.

Weed free check (1.04 t/ha), farmers' practice of two hand weeding (1.01 t/ha) and application of quizalofop-ethyl 31.25 g/ha + imazethapyr 62.5 g/ha (0.98 t/ha) recorded significantly higher seed yield as compared to remaining treatments and these three treatments were at par with each other, recorded more than 200% higher yield over unweeded check (Table 2). Application of quizalofop-ethyl 31.25 g/ha + imazethapyr 62.5 g/ha as tank mix registered higher net monetary returns (` 27582/ha), followed by farmers practice of two hand weeding at 15 and 30 DAS (` 26260/ha) and weed free check (` 26160/ ha). Higher benefit-cost ratio (BCR) of 3.4 was obtained with tank mix application of quizalofop-ethyl + imazethapyr at 31.25 + 62.5 g/ha as compared to farmers' practice (2.9) mainly due to higher cost of manual weeding.

SUMMARY

Tank mix application of quizalofop-ethyl 31.25 g/ha + imazethapyr 62.5 g/ha in 250 litre of water (2.5 ml each/litre of water) at 15 days after sowing was found most effective in controlling all type of weeds including volunteer paddy besides higher productivity and profitability of irrigated blackgram.

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Short communication

Management of common vetch and other weeds in relay crop of black gram

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Key words: Blackgram, Management, Relay crop, *Vicia sativa*, Weeds

Cultivation of blackgram (*Vigna mungo*) as a relay crop in Krishna-Godavari and North Coastal Zones of Andhra Pradesh in India is an unique system where sprouted seeds of blackgram are broadcasted in standing rice crop two to three days prior to its harvest and the crop sown in this system survives on residual moisture and fertility only. As this system does not ensure uniform plant population and being short duration and initially slow growing, crop is heavily infested with many weeds, which compete with the crop during initial growth stage resulting in yield loss of 45 to 60% (Sasikala *et al*. 2014). Continuous use of post-emergence grassy herbicides has resulted in weed flora shift towards broad-leaved weeds like common vetch (*Vicia sativa* L.), which is one of the problematic weeds in relay crop of blackgram, spreading vigorously in recent years in the North coastal zone of Andhra Pradesh. (Jayalalitha and Rao 2006). Keeping this in view, the present experiment was conducted to find out the most suitable weed management practice for control of this location specific weed

A field experiment was conducted during *Rabi*, 2015-16 at the Agricultural College Farm, Naira, Andhra Pradesh. The soil was sandy clay loam in texture with a neutral pH of 7.13 and EC of 0.10 dS/m, medium in organic carbon (0.54%), low in available nitrogen (173.4 kg/ha), high in available phosphorus (46.1 kg/ha) and potassium (326.1 kg/ha). The seeds of blackgram cultivar '*LBG 645*' 25 kg/ha were soaked in water for about eight hours and were dibbled at 30 × 10 cm apart. The experiment comprising of 10 treatments (Table 1) was laid out in a randomized block design replicated thrice. In case of treatments involving sand mix application, the required quantity of herbicide was mixed in dry sand 50 kg/ha and then broadcasted uniformly immediately after sowing of blackgram followed by water spray 500 l/ha as pre-emergence application. The crop survived entirely on residual fertility and moisture only. The data on weed density and dry weight was subjected to square root transformation using $\sqrt{x + 0.5}$ to reduce large variations.

The important weed flora observed in this investigation were *Ammania baccifera*, *Cardanthera uliginosa*, *Ludwigia parviflora*, *Trianthema portulacastrum*, *Hydrolea zeylanica*, *Vicia sativa*, *Cardiospermum helicacabum*, *Chrozophora rottleri*, *Gnaphalium polycaulon*, *Grangea maderaspatana* and *Phyllanthus maderaspatensis*. *Vicia sativa* was the dominant weed among all the species at all the stages of observation, which consisted about 75% of total weed population.

Among the weed control treatments at 60 DAS, significantly lower density, dry weight and the highest weed control efficiency (WCE) of 91% of *Vicia sativa* was observed with acifluorfen + clodinafop-propargyl 0.4 kg/ha as post-emergence at 25 DAS , which was at par with other treatments and also with hand weeding at 15 and 30 DAS, which had the lowest density and dry weight (Table 1). Significantly higher density and dry weight of other weeds was observed in weedy check treatment while the lowest density, dry weight and highest weed control efficiency of 80% of other weeds were recorded with acifluorfen + clodinafop-propargyl 0.4 kg/ha as post-emergence at 25 DAS comparable with hand weeding at 15 and 30 DAS. Effectiveness of acifluorfen + clodinafop-propargyl in controlling all weeds except *Cuscuta* in rice fallow blackgram was also reported by Rao (2015). Among the herbicide treatments, the highest seed (762 kg/ha) and haulm yield (1.52 t/ha) were obtained with acifluorfen + clodinafop-propargyl 0.4 kg/ha as post-emergence at 25 DAS and it was at par to its lower doses 0.35 kg and 0.3 kg and also was comparable with hand weeding at 15 and 30 DAS (Table 2). Reduction in seed yield in relay crop of blackgram to an extent of 75% due to weed competition was also reported by Rao (2008a). Regarding economics, the treatment that received the highest dose (0.4 kg/ha) of acifluorfen + clodinafop-propargyl resulted in highest net returns (` 53240/ha), which was closely followed by its lower doses (0.35 kg/ha and 0.3 kg/ha) but the highest benefit : cost ratio (2.28) was obtained with acifluorfen + clodinafop-propargyl 0.3 kg/ha as post-emergence at 25 DAS.

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Table 1. Density, dry weight and weed control efficiency of *Vicia sativa* and other weeds as influenced by weed control treatments in relay crop of blackgram at 60 DAS

Treatment	Density of *Vicia sativa* (no./m^2)	Dry weight of *Vicia sativa* (kg/ha)	Weed control efficiency of *Vicia sativa*	Density of other weeds (no./m^2)	Dry weight of other weeds (kg/ha)	Weed control efficiency of other weeds
Hand weeding at 15 and 30 DAS	5.04 (25)	0.44 (2.1)	93	4.00 (17)	0.46 (2.1)	90
Pendimethalin 1 kg/ha as sand mix application	13.65 (191)	1.51 (22.9)	16	10.80 (116)	1.10 (12.1)	34
Imazethapyr 75 g/ha as sand mix application	13.39 (182)	1.22 (14.9)	41	10.30 (106)	1.06 (11.1)	39
Imazethapyr 50 g/has PoE at 20 DAS	13.09 (175)	1.14 (13.0)	49	10 (100)	0.88 (7.6)	57
Acifluorfen + clodinafop-propargyl 0.2 kg/ha as PoE	7.77 (60)	0.65 (4.2)	82	7.2 (51)	0.74 (5.5)	67
Acifluorfen + clodinafop-propargyl 0.25 kg/has PoE	7.27 (52)	0.64 (4.1)	83	6.3 (45)	0.68 (4.7)	71
Acifluorfen + clodinafop-propargyl 0.3 kg/ha as PoE	7.00 (49)	0.54 (2.9)	89	5.2 (27)	0.64 (4.2)	75
Acifluorfen + clodinafop-propargyl 0.35 kg/ha as PoE	6.55 (44)	0.53 (2.8)	90	4.8 (23)	0.62 (3.8)	78
Acifluorfen + clodinafop-propargyl 0.4 kg/ha as PoE	6.00 (42)	0.50 (2.4)	91	4.5 (20)	0.57 (3.3)	80
Weedy check	14.12 (208)	1.65 (27.6)	-	11.20 (127)	1.40 (20.0)	-
LSD (P=0.05)	3.07	0.25	15.77	2.28	0.24	15.54

Data were subjected to square root transformation $\sqrt{x+0.5}$. Figures in parenthesis are original values

Table 2. Yield attributes, yield and economics as influenced by weed control treatments in relay crop of blackgram

Treatment	Branches / plant	Pods/ plant	Seeds/ pod	Test weight (g)	Seed yield (kg/ha)	Haulm yield (t/ha)	Net returns (x10^3 `/ha)	BCR (Rs.)
Hand weeding at 15 and 30 DAS	9.8	11.0	6.4	4.7	812	1.64	52.19	1.75
Pendimethalin 1 kg/ha as sand mix application	5.8	8.4	5.8	4.3	520	1.05	30.19	1.35
Imazethapyr 75 g/ha as sand mix application	6.2	8.6	5.8	4.7	540	1.12	32.81	1.51
Imazethapyr 50 g/haasPoE at 20 DAS	6.3	9.4	5.9	4.3	550	1.12	33.31	1.50
Acifluorfen + clodinafop-propargyl 0.2 kg/ha as PoE	7.3	9.9	6.1	4.5	620	1.26	40.41	1.82
Acifluorfen + clodinafop-propargyl 0.25 kg/haasPoE	8.5	10.0	6.1	4.6	650	1.36	43.09	1.91
Acifluorfen + clodinafop-propargyl 0.3 kg/ha as PoE	9.1	10.9	6.2	4.4	745	1.47	52.28	2.28
Acifluorfen + clodinafop-propargyl 0.35 kg/ha as PoE	9.2	10.9	6.2	4.6	755	1.51	52.93	2.27
Acifluorfen + clodinafop-propargyl 0.4 kg/ha as PoE	9.3	10.9	6.3	4.6	762	1.52	53.24	2.25
Weedy check	4.9	8.0	5.5	4.4	426	0.85	22.57	1.10
LSD (P=0.05)	0.79	1.15	NS	NS	99	0.19	9.88	0.44

Seed: ` 100/kg, Haulm: ` 0.50/kg.

SUMMARY

Broad-leaved weeds like common vetch (*Vicia sativa* L.), has become a problematic weeds in relay crop of blackgram, in recent years in the North coastal zone of Andhra Pradesh. Present experiment was conducted to find out the most suitable weed management practice for control of this location specific weed. Post-emergence application of acifluorfen + clodinafop-propargyl 0.3 kg/ha was found to be most effective and economical in managing *Vicia sativa* and other weeds in rice fallow blackgram as an alternative to manual weeding.

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Short communication

Weed smothering in jute with green gram intercropping

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Key Words: Green gram, Intercropping, Jute, Smothering, System productivity, Weed management

Jute (*Corchorus olitorius* L.), a natural fibre crop, is grown by resource poor farmers of South East Asian countries namely, India, Bangladesh, Nepal, Myanmar, Thailand *etc*. Of late, jute is losing its commercial significance due to the stiff competition from its plastic counterparts. The net return from jute cultivation is poor owing to its high cost of cultivation (Ghorai 2008). About 40 per cent of the total cost of cultivation of jute goes in weeding process alone (Ghorai 2013). The fibre yield loss up to 90% has also been recorded if not weeded at proper time. Selective herbicides commercially used in jute can control monocots and some dicot weeds only (Ghorai *et al.* 2015). Inclusion of pulses as intercrop in jute smothered dicot and sedge weeds up to 54% (Ghorai *et al.* 2010). Moreover, this system provides nutritional security, improve soil health and strengthen the economy of poverty stricken jute farmers. There is also scanty information about viable intercropping system in jute with greengram. Thus, the experiment was conducted to develop suitable protocol for intercropping jute with greengram (1:1) that will smother weeds, increase system productivity and strengthen jute farmers' economy. Weed control efficiency of this intercropping system was also compared with other weed control methods.

The experiment was conducted at ICAR-CRIJAF farm in randomised block design (RBD) with eleven treatments (Table 1) replicated thrice during 2011-2013. The experimental soil was sandy clay loam in texture with 44% sand, 28% silt and 28% clay. Its available nitrogen, phosphorus and potassium content was 180, 34 and 133 kg/ha, respectively. The date of sowing varied from 19th to 23rd March in different years. For intercropping, jute cultivar '*JRO-204*' and green gram cultivars of different maturity like '*PM4* (65 days), '*PM5*' (55-60 days), '*RMG-62*' (55-60 days), '*Sukumar*' (55-60 days) were sown alternately in 1:1 ratio at different spacings (25-35 cm) in between jute row. Jute and green gram seed rates were 3.5 and 15-25 kg/ha, respectively. One post sowing irrigation was applied for proper germination of green gram and jute seeds. Butachlor 50 EC 1.0 kg/ha was used as pre-emergence herbicide in jute and green gram intercropping system. CRIJAF nail weeder (Patent application number: 386/KOL/2010, dated 5/4/2010) was used for mechanical weed control, line arrangement and soil mulching in broadcast jute. CRIJAF herbicide applicator (Patent application number: 319/KOL 2010 dated 28/3/2010) was used for directed application of glyphosate 41% SL in inter row space. As check, two manual weeding was used. For crop nutrition, a basal dose of N:P:K::20:70:70 was applied for intercrop. Top dressing of nitrogen was done 60 kg/ha after green gram harvest (55-65 days) with one irrigation. For sole jute, dose of fertilizers was N:P:K::60:30:30 . Irrigation was applied during top dressing after harvest of pulses near 55-60 days after sowing.

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On the same day of sowing, chloropyriphos was sprayed to prevent loss of green gram seed from bird and insect damage. Bavistin 2 g/l and imidacloprid 0.3 g/l together were sprayed at 15 days intervals to save pulse crop from sucking insect attack and fungi attack. Emamectin benzoate was sprayed to control pod borer 0.3 g/lit. Deltamehrin 1.5 ml/l was sprayed to control pulse pod sucking bugs. Green gram was harvested by uprooting or picking pods at 90-100 per-cent pod maturity.

Weed flora

The weed flora found in jute field consisted of i) grasses: *Echinochloa colona* (barnyard grass), *Digitaria* spp., *Eleusine* spp. and *Cynodon dactylon, Brachiaria repens, Setaria* spp, *Brachiaria ramosa*; ii) sedges: *Cyperus rotundus, Cyperus difformis* and iii) broad-leaved weeds: *Eclipta alba*, *Phylanthus niruri*, *Portulaca* spp. *Trianthema* spp., *Euphorbia hirta*, *Celosia argentia*.

Weed control and economics

Weed control efficiency of intercropping system was much higher (68-82%) than conventional manual weeding twice (63.62%). Benefit: cost ratio under this system varied between 2.2 to 2.46 over 1.80 only in manual weeding process. CRIJAF nail weeder and

Table 1. Fibre equivalent yield, weed control efficiency and economics of different weed management practices (pooled data of three years)

Treatment	Fibre equivalent yield# (t/ha)	Weed control efficiency (%)	Net return (x10^3 `/ha)	Benefit cost ratio
Jute (30 cm) + *PM-4* + butachlor 50 EC1 kg /ha +1HW	4.95	71.61	90.40	2.25
Jute (35 cm) + *PM-5* + butachlor 50 EC 1 kg /ha +1HW	4.81	68.04	86.81	2.23
Jute (30 cm) + sukumar + butachlor 50 EC 1 kg /ha +1HW	4.71	82.19	840.27	2.19
Jute (25cm) + *RMG-62*, butachlor 50 EC 1 kg/ha +1HW	5.26	69.27	102.21	2.46
Jute (25 cm)+ CRIJAF nail weeder twice (5 and 21 DAS) +1HW	3.91	84.33	65.61	2.07
Open furrow (25 cm) sowing of jute + butachlor 50 EC 1 kg +1HW	3.59	57.19	52.42	1.83
Butachlor 50 EC 1 kg/ha + glyphosate 0.8 kg SL/ha at 21 DAS (directed spray using hood) + 1 HW (25 cm)	3.77	82.19	62.74	2.06
Two manual weeding in jute (25 cm), 15 and 21 DAS	3.90	63.62	56.19	1.80
Jute + okra (cv. *Shakti*) [(2:1, 25 cm, okra sown 3rd week of November). + 2 HW)	5.67	81.93	105.77	2.31
Unweeded control (25 cm)	1.30	0	-19.45	0.69
Glyphosate 1.23 l SL/ha by CRIJAF herbicide applicator at 20 DAS (25 cm) + 1 HW	4.08	81.93	75.46	2.28
LSD. (P=0.05)	0.21	15.25	11.87	0.262

HW:- Hand weeding; #inclusive of jute stick and pulse waste

herbicide applicator recorded higher weed control efficiency (82 to 84%) and B:C ratio (2-2.28) over conventional manual weeding twice. The green gram in intercropping system produced 2 t/ha of green gram wastes (average nitrogen 2.35%, analysed using 2030 Kjeltech analyser unit, Foss Tecator) which is equivalent to 10 tonnes of farmyard manure (FYM). If incorporated in jute soil, it will improve the soil health. It can also be used as nutritious fodder. The system has been found to be remunerative and sustainable for resource poor jute farmers.

System productivity

Jute-green gram intercropping system improved the system productivity. The jute equivalent yield varied from 4.7 to 5.3 t/ha where sole jute production was around 3.9 t/ha only (Table 1). Intercropping system recorded 2.8-3.0 t jute fibre/ha along with 0.7-1.0 t/ha pulse grain (depending on grain size). Intercropping system of jute (25 cm) + ‘*RMG 62*’ recorded significantly higher jute equivalent yield (JEY). The comparatively short stature of *‘RMG-62’* fitted well in normal jute spacing (25 cm). Higher price of this grain (small shiny and polished) increased the JEY compared to other green gram varieties.

SUMMARY

Jute equivalent yield varied from 4.7 to 5.3 t/ha and was profitable over sole cropping of jute, 3.9 t/ha only. Weed control efficiency of intercropping system was 68-82% over 63.6% in conventional manual weeding twice. Benefit-cost ratio of jute and green gram intercropping system varied between 2.2 to 2.46 over 1.8 in conventional manual weeding twice. CRIJAF nail weeder and CRIJAF herbicide applicator recorded higher weed control efficiency (82 to 84%) and B:C ratio (2-2.28) over conventional manual weeding twice (63.62% and 1.80). This jute and green gram intercropping system will improve jute farmers economy, provide protein security to rural mass, and take care of soil and animal health in rural sector.

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Short communication

Pre-emergence herbicides for weed management in sesame

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Key Words*:* Broadcast sesame, Pre-emergence herbicides, Seedling vigour index, Phytotoxicity

The productivity of sesame (*Sesamum indicum* L) in India is the lowest in the world due to its cultivation in marginal and sub-marginal soils under rainfed situation with poor agronomic management practices (Bhaduaria 2012). Among the several constraints in sesame production, weed infestation is one of the major factors limiting the yield of sesame. Sowing of sesame seeds is very difficult as the seeds are very small and need to be placed precisely at optimum soil depth for good germination and establishment. The most common method of establishment of sesame is broadcasting, where the seeds are placed at shallow depth. The selectivity of pre-emergence herbicides under this condition is quite different from the line sowing. It is common that some of the crop seeds in broadcasting are placed on the surface of the soil and get damaged due to phytotoxicity of soil applied pre-emergence herbicide. The magnitude of phytotoxicity of commonly used pre-emergence herbicides to sesame seeds vary with type of soil, depth of sowing, dose of pre-emergence herbicides applied and moisture content of the soil or quantity of rainfall received after its application. These parameters significantly influence the selectivity mechanism and leaching behaviour of the pre-emergence herbicides. Due to shallow depth of sowing while broadcasting, the pre-emergence applied herbicides may come in close contact with the sesame seed, results in increased phytotoxicity or stand loss (Grichar *et al.* 2001).

Pre-emergence application of pendimethalin 1.0, 1.5, 2.0 and 2.5 kg/ha showed phytotoxicity rating of 4.8, 4.9, 6.0 and 6.2, respectively in sesame at 2 weeks after sowing (WAS) on sandy loam soils in 1-10 scale where 1= no crop injury and 10= complete crop kill (Imoloame *et al*. 2011). On the contrary, pre-emergence application of alachlor, fluchloralin and trifluralin at 1.5, 1.0 and 1.0 kg/ha, respectively in line sown sesame on loamy sands did not show any phytotoxicity to the crop (Sheroran *et al*. 2012). Phytotoxicity of pre-emergence herbicides on sesame was also reported by some researchers. The erratic behaviour of many soil applied herbicides was attributed due to method of establishment and rainfall or moisture content, which markedly influences the herbicide toxicity to sesame (Martin 1995). There is a paucity of data on seedling vigour index of the broadcast sesame to pre-emergence herbicides. The present study was conducted to know the response of broadcast sesame to some pre-emergence herbicides and to know their suitability.

A pot culture experiment was conducted at S.V. Agricultural College, Tirupati campus of Acharya N.G. Ranga Agricultural University, Andhra Pradesh during January, 2015 in order to estimate the effect of pre-emergence herbicides on germination per cent and seedling vigour index of the broadcast sesame in a completely randomized design with four treatments and five replications**.** The treatments consisted of pre-emergence application of pendimethalin 750 g/ha, oxyfluorfen 75 g/ ha, oxadiargyl 75 g/ ha and control. Circular plastic tubs (pots) of 46 cm diameter with a depth of 15 cm were selected and were filled with approximately 25 kg of soil. The soil used for the present experiment was sandy loam in texture with low in organic carbon (0.45%), available nitrogen (194 kg/ha) and available phosphorus (24 kg/ha) and medium in available potassium (175 kg/ha) with a soil P^H of 6.4. Profuse watering was given to all the tubs after filling the soil to bring the soil under saturation and settling of the soil particles in it. The excess water was removed through drainage holes made at bottom of the tubs. The topsoil in the tub was tilled with hand operated racker to get fine tilth at field capacity to facilitate broadcasting of sesame seeds**.** Fifty seeds of sesame were broadcast in each plastic tub followed by racking with hand operated racker to simulate the conditions as that of field**.** All the pre-emergence herbicides were applied immediately after sowing at recommended doses. Pre-emergence herbicides, *viz*. pendimethalin, oxyfluorfen and oxadiargyl were

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applied at 5, 0.6 and 0.18 ml/litre of water, respectively with the help of one litre mini hand operated sprayer as per the treatment. The data on number of seeds germinated, root and shoot length of sesame was recorded at 10 days after sowing. Phytotoxicity rating on the crop was observed at 10 days after pre-emergence application of herbicides in 0-10 scale where '0' indicate no crop damage and '10' indicate complete crop damage. The germination percentage and seedling vigour index (Abdul-Baki and Anderson 1973) of sesame were calculated based on the following formulae.

$$\text{Germination percentage} = \frac{\text{Number of seeds germinated}}{\text{Number of seeds kept for germination}} \times 100$$

$$\text{Seedling vigour index} = \text{Germination percentage} \times \text{Seedling length (cm)}$$

Germination percentage

The lowest germination percentage of broadcast sesame was recorded with pre-emergence application of oxadiargyl 75 g/ha, which was significantly lesser than the rest of the pre-emergence of herbicides tested (Table 1). Nethra and Jagannath (2011) also reported that the seed germination, length of the radical and plumule were severely affected with increased concentration of oxadiargyl in sunflower and maize crops under hydroponics. Pre-emergence application of pendimethalin 750 g/ha resulted in the highest germination (62.8%), which was comparable with pre-emergence application of oxyfluorfen 75 g/ha (60.2%).The decrease in germination of sesame with oxadiargyl, pendimethalin and oxyfluorfen treated plots were by 31.5, 22.2 and 18.8%, respectively compared to control.

Seedling length

Among the pre-emergence herbicides tested, oxadiargyl 75 g/ha resulted in the highest root length of sesame at 10 DAS, which was at par with oxyfluorfen and both of them were significantly higher than the pre-emergence application of pendimethalin (Table 1). Oxadiargyl may inhibit the protophorphyrinogen oxidase, a key enzyme responsible for the biosynthesis of precursor substances for chlorophyll in plants rather than inhibiting the root growth and thus produced longer roots. The lowest root length of sesame was recorded with pendimethalin as it act as root inhibitor rather than shoot by disturbing cell division. The reduction in root length was 29.0, 19.4 and 15.0% with pre emergence application of pendimethalin, oxyfluorfen and oxadiargyl applied 750, 75 and 75 g/ha, respectively (Fig.1).

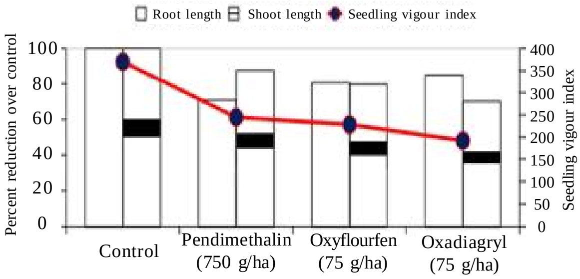

Fig. 1. Effect of pre-emergence herbicides on root / shoot growth and seedling vigour index in broadcast sesame

Among the herbicides tested, the highest shoot length of sesame was produced with pre-emergence application of pendimethalin, which was significantly higher compared to oxyfluorfen. Pre-emergence application of oxadiargyl, oxyfluorfen and pendimethalin reduced the shoot length by 29.8, 20.2 and 12.3% compared to control (Fig.1). Pre-emergence application of oxadiargyl might inhibited the chlorophyll synthesis in treated plots resulted in bleaching of the leaves and finally reduced the shoot growth. Similar results were also reported by (Nethra and Jagannath, 2011).

Seedling vigour index

Seedling vigour index of sesame was significantly influenced by pre-emergence application of herbicides as it is the product of the germination percent and seedling length. All the herbicides tested in the present study significantly reduced the germination percent and length of the seedling. Among the herbicides tested, the highest seedling vigour index of broadcast sesame was observed with pre-emergence application of pendimethalin 750 g/ha (247.7), which was comparable with oxyflurofen 75g/ha (228.2). On contrary, Imoloame *et al.* (2011) reported that pre-emergence application of pendimethalin at higher dose significantly reduced the crop vigour index of sesame. The lowest seedling vigour index of sesame with pre-emergence application of oxadiargyl 75 g/ha was due to reduced germination percentage and decreased seedling length of sesame as oxadiargyl showed phytotoxicity on sesame seedlings (Table 1).

Phytotoxicity

Among the pre-emergence herbicides, oxadiargyl 75 g/ha showed the phytotoxicity rating of 6.0 in 0-10 scale where '0' indicate no injury and '10' indicate complete crop damage. Pre-emergence application of oxyfluorfen 75 g/ha showed phytotoxicity rating of '4' followed by pendimethalin

Table 1. Effect of pre-emergence herbicides on seedling length, vigour index and phytotoxicity on broadcasted sesame

Treatment	Germination (%)	Seedling length (cm)		Seedling vigour index	Phytotoxicity rating
		Root length	Shoot length		
Pendimethalin 750 g/ha	62.8	1.32	2.56	244.7	3.00
Oxyfluorfen 75 g/ha	60.2	1.50	2.33	228.2	4.00
Oxadiargyl 75 g/ha	53.0	1.58	2.05	192.4	6.00
Control	77.4	1.86	2.92	370.0	0.00
LSD (P = 0.05)	4.32	0.10	0.16	18.2	-

750 g/ha with phytotoxicity rating of '3'. The phytotoxicity effect of oxyfluorfen and pendimethalin on sesame seedlings were recovered within 15 days after herbicide application.

SUMMARY

The study was conducted at S.V. Agricultural College, Tirupati during summer 2015 in a complete randomized design with four treatments consisting of pre-emergence application of pendimethalin 750, oxyflourfen and oxadiargyl 75 g/ha each and control replicated five times. Among the herbicides tested, pre-emergence application of pendimethalin 750 g/ha recorded the highest seedling vigour index followed by oxyfluorfen 75 g/ha in broadcast sesame on sandy loam soils. Pre-emergence application of oxadiargyl 75 g/ha showed phytotoxicity rating of "6" in broadcast sesame.

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Short communication

Weed management in cotton with pre- and post-emergence herbicides

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Weed control method effective in one set of conditions may not be effective in other set of conditions due to fertility variation and irrigation water availability (Nadeem *et al.* 2013). Herbicides have remained the principal tool and foundation of most effective weed control programs (Norsworthy *et al.* 2012). With increasing availability of new chemicals, their weed control efficiency needs to be evaluated. Generation of such information through field experimentation under site-specific conditions is very crucial for guiding cotton growers.

An experiment was conducted in 2014 at Punjab Agricultural University, Research Station, Faridkot, Punjab (30 ^{0} 40’N and 74 ^{0} 44 ’E). The 10 weed control treatments (*i.e.* pendimethalin 1.0 kg/ha as pre-emergence + one hoeing, trifluralin 1.2 kg /ha PPI + one hoeing, quizalofop-ethyl 50 g/ha at 2-4 weed leaf stage + one hoeing, pendimethalin 1.0 kg/ha as pre-emergence + quizalofop-ethyl 50 g/ha at 2-4 weed leaf stage + one hoeing, pyrithiobac-sodium 62.5 g/ha at 2-4 weed leaf stage + one hoeing , pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha at 2-4 weed leaf stage + one hoeing, glyphosate 1.0 kg/ha as directed spray at 45 DAS, weed free check, farmer’s practice and weedy check/control) were evaluated in randomized block design having four replications. Hand hoeing in all the treatments was given at 60 DAS while, in farmer’s practice, one hand hoeing at 60 DAS followed tractor hoeing at 90 DAS and application of glyphosate 0.5 kg/ha as directed spray to emerged weeds during rainy season. Weed population and biomass was recorded from quadrat measuring 50 x 50 cm and expressed per square meter. Data on growth, yield and other parameters were recorded from five randomly selected plants in each treatment plot while seed cotton yield (SCY) was recorded from whole plot.

Effect on yield attributes and seed cotton yield

Sympods per plant were highest in weed free check (30.0) though statistically at par with pendimethalin 1.0 kg/ha + quizalofop-ethyl 50 g/ha + one hoeing (28.3) and pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha + one hoeing (27.1) while the statistically least value was recorded in weedy check (19.5). This might be due to the favorable conditions that existed during the early growth period owing to low weed population resulting in vigorous growth and development leading to higher number of sympods per plant. As a result of all these, significantly higher biomass was recorded in case of weed free plots (18.95 t/ha) as compared to all tested treatments except for pendimethalin 1.0 kg/ha + quizalofop-ethyl 50 g/ha + one hoeing (17.47 t/ha) with which it was at par. Statistically least biomass was recorded under weedy check (11.02 t/ha) which might be due to the maximum crop-weed competition.

Highest number of bolls per plant were observed in weed free check (54.5) though it was statistically at par with pyrithiobac-sodium 62.5g/ha + quizalofop-ethyl 50 g/ha + one hoeing (50.5) followed by pendimethalin 1.0 kg /ha + quizalofop-ethyl 50 g/ha + one hoeing (49.0). Statistically least boll count was recorded in weedy check (33.0). Boll weight was highest under pendimethalin 1.0 kg/ha + one hoeing (4.07 g) while the minimum value was observed in weedy check (3.27).

Improved yield attributes such as bolls/plant and boll weight collectively resulted in highest seed cotton yield (3.55 t/ha) in weed free check, though it was statistically at par with pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha + one hoeing (3.52 t/ha), pendimethalin 1.0 kg/ha + quizalofop-ethyl 50 g/ha + one hoeing (3.40 t/ha), however significantly least seed cotton yield (1.92 t/ha) was recorded in weedy check (Table 1). This might be due to the competition offered by weeds for various resources like light, water, nutrients *etc.* which retarded cotton growth. Panwar *et al.* (1995) also reported that weed control practices increased number of sympods, bolls per plant, boll weight and seed cotton yield. Weedy check recorded least yield because of severe weed

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competition as revealed by highest weed population (70.0) and maximum weed dry matter (340.1 g). The increased crop-weed competition and poor availability of various growth factors to cotton crop plants have been clearly reflected in reduced yield contributing parameters such as boll number and boll weight. These results are in close conformity with the results of Patel *et al* (2014). Highest ginning out turn percentage (GOT%) was recorded under pendimethalin 1.0 kg /ha + one hoeing (33.8) while the least was found in weedy check (31.5) indicating deterioration of quality under weed infestation (Table 1).

Effect on weed dry matter, weed control efficiency and monetary parameters

Dry weight of weeds is an important measure showing the extent to which weeds have competed with the main crop and how weed growth has been affected by tested weed control practices. Non-significant differences for initial weed dry matter indicated uniformity of weed distribution among treatment plots. Results indicated wide variation among tested treatments for weed dry matter as well as weed control efficiency (Table 1). Among chemical treatments, pendimethalin 1.0 kg /ha + quizalofop-ethyl 50 g/ha + one hoeing resulted in least weed dry matter (98.6 g/m^2) followed by pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha + one hoeing (133.2 g/m^2) while among all treatments under study, the least value was recorded in weed free check (32.8 g/m^2).This was due to the fact that frequent hoeing and inter-cultural operations allowed minimum weeds to grow and consequently weed free plots recorded least weed dry weight. Shahzad *et al.* (2012) and Nadeem *et al.* (2013) also reported that hand weeding and herbicidal treatments reduced the weed infestation efficiently. Weed control efficiency was highest under weed free check (90.3%) followed by pendimethalin 1.0 kg/ha + quizalofop-ethyl 50 g/ha + one hoeing (71.0%) and least under farmer's practice (25.5%). Our results were in accordance with Naseer-ud-Din *et al.* (2011).

Cost of cultivation was observed to be significantly higher (` 50802/ha) under weed free check. This was higher due to the fact that maximum number of manual/hoeing operation were performed to check the growth of weeds besides more cost incurred on picking seed cotton yield due to its relatively more quantity. Contrary to it, weedy check recorded least cost of cultivation (` 34502/ha). Highest net returns were observed under pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha + one hoeing (` 100916/ha) followed by weed free plots (` 98393/ha) and pendimethalin 1.0 kg/ha + quizalofop-ethyl 50 g/ha + one hoeing (` 97018/ha) while the least returns were recovered from the crop under weedy conditions (` 46093/ha). B:C ratio was found to be highest for Trifluralin 1.2 kg/ha PPI + one hoeing (2.15) followed by pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha + one hoeing (2.14) with statistically least value for weedy check (1.31).

Table 1. Seed cotton yield, yield attributes and other ancillary parameters as affected by different weed management treatments

Treatment	Initial weed dry matter (g/m^2) 50 DAS	Final weed dry matter (g/m^2)	WCE (%)	Seed cotton yield (t/ha)	Sympods /plant	Bolls/ plant	Boll weight (g)	GOT (%)	Net returns (x10^3 `/ha)	B:C ratio
Pendimethalin 1.0 kg/ha as PE + one hoeing	32.0 (34.2)	174.2 (13.2)	48.8	3.21	22.9	41.5	4.07	33.8	91.40	2.10
Trifluralin 1.2 kg/ha PPI + one hoeing	40.0 (39.1)	172.0 (13.0)	49.4	3.32	24.5	44.0	3.80	32.7	95.62	2.15
quizalofop-ethyl 50 g/ha at 30 DAS + one hoeing	30.6 (32.7)	167.9 (12.9)	50.6	3.06	25.3	44.7	3.67	33.2	85.98	2.00
Pendimethalin 1.0 kg/ha as PE + quizalofop-ethyl 50 g/ha + one hoeing	43.6 (41.3)	98.6 (9.9)	71.0	3.40	28.3	49.0	3.80	33.1	97.02	2.11
Pyrithiobac-sodium 62.5 g/ha at 20-30 DAS + one hoeing	42.6 (406)	216.5 (14.7)	36.3	3.21	25.8	43.1	3.75	33.5	90.88	2.07
Pyrithiobac-sodium 62.5g /ha + quizalofop-ethyl 50 g/ha at 2-4 weed leaf stage + one hoeing	41.3 (39.9)	133.2 (11.5)	60.8	3.52	27.1	50.5	3.55	33.5	100.92	2.14
Glyphosate 1.0 kg/ha as directed spray at 45 DAS	48.6 (44.1)	214.2 (14.6)	37.0	2.91	24.6	42.1	3.75	32.3	81.07	1.95
Weed free check	40.0 (39.1)	32.8 (5.8)	90.3	3.55	30.0	54.5	3.75	32.6	98.39	1.93
Weedy check	41.3 (39.9)	340.1 (18.4)	-	1.92	19.5	33.0	3.27	31.5	46.09	1.31
Farmers practice	40.6 (39.5)	253.5 (15.9)	25.5	3.04	22.7	38.8	3.90	31.7	85.46	2.02
LSD (P=0.05)	NS	1.4	-	0.47	3.1	8.3	0.36	1.36	17.10	0.28

Data on weed dry matter has been subjected to square root transformation; Figures in parenthesis are means of transformed values; GOT= Ginning out turn

Pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha + one hoeing could provide effective control of weed in cotton

SUMMARY

Field experiment was conducted during *Kharif* 2014 to evaluate weed control efficiency of different herbicides for weed management and their effect on cotton crop. Highest seed cotton yield (3.55 t/ha) was recorded in weed free plots followed by pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha + one hoeing (3.52 t/ha) owing to improved number of bolls per plant and boll weight. Statistically least yield was recorded under weedy check (1.92 t/ha). Weed control efficiency (WCE) was highest under weed free check (90.3%) followed by pendimethalin 1.0 kg/ha + quizalofop-ethyl 50 g/ha + one hoeing (71.0%), whereas minimum for weedy check (25.5%). Net returns (` 100916/ha) and B:C ratio (2.14) were highest for pyrithiobac-sodium 62.5 g/ha + quizalofop-ethyl 50 g/ha + one hoeing. Therefore, this set of chemicals combination along with cultural practices could be the practical solution for economically efficient and effective weed management in cotton.

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Short communication

Yield and nutrient uptake in soybean as influenced by weed management

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Soybean (*Glycine max* (L.) Merrill.) often designated as miracle crop of twenty first century, contains about 20% of oil, 40% high quality proteins, 23% carbohydrates and reasonable amount of minerals, vitamins and dietary fibres. The initial slow growth of soybean with lateral spread, offers severe infestation of a large number of weeds which reduces the yield to an extent of 31 to 84% (Kachroo *et al.* 2003). The present investigation was undertaken to study the extent of nutrients depletion by the crop and weed under different weed management practices.

A field experiment was carried out at Rajasthan College of Agriculture, MPUAT, Udaipur during *Kharif* 2014 to evaluate the effect of weed management practices on nutrient uptake by soybean crop, weeds and their combine uptake. The soil of the experiment plot was clay loam, alkaline in reaction, medium in nitrogen and phosphorus and high in potassium content. The experiment was laid out in randomized block design comprising of 14 treatments. Soybean variety '*JS-9560*' was sown on 16th July, 2014 by drilling 80 kg seed/ha at 30 cm row spacing. Observations on weed count at 50 DAS was recorded by using a quadrat measuring 50 × 50 cm at two randomly selected spots in each plot and their average was taken as weed dry matter and converted into kg/ha. Weed samples were collected at 75 DAS, while crop samples collected at harvest from each experimental unit and oven dried at 70 °C till a constant weight was recorded and grinded in laboratory mill. These samples were analyzed for N and P content following standard procedure. The uptake of nutrient was estimated by following formula.

Weed biomass

The experimental field was heavily infested with mixed flora of broad–leaved, sedge and grassy weeds, *viz. Trianthema portulacastrum, Commelina benghalensis, Parthenium hysterophorus, Amaranthus viridis, Digera arvensis, Cynodon dactylon, Echinochloa colona* and *Cyperus rotundus.*

Data (Table 1.0) revealed that all the weed management treatments significantly reduced dry weight of monocots, dicots and total weeds as compared to weedy check. The minimum total weed dry matter (146.0 kg/ha) at 75 DAS was observed under weed free treatment which was closely followed by pre-emergence application of pendimethalin 750 g/ha + hand weeding at 30 DAS (431.7 kg/ha) and two hand weeding treatment at 15 and 30 DAS (475.6 kg/ha) as compared to weedy check (1.88 t/ha). The superiority of pre-emergence application of pendimethalin 750 g/ha + hand weeding at 30 DAS was because of the fact that the emergence of early growth of weeds was inhibited by pre-emergence application of soil applied herbicide and later emerging weeds were effectively controlled by hand weeding performed at 30 DAS. Thus, this treatment provided long weed free period compared to their application alone. While in case of two hand weeding, weed growth of early flush of weeds was checked by hand weeding performed at 15 DAS and second or late emerging weeds were effectively controlled by second hand weeding which was done at 30 DAS. The per cent reduction in total biomass of weeds due to weed free, pre-emergence application of pendimethalin 750 g/ha + one hand weeding at 30 DAS, two hand weeding at 15 and 30 DAS and pre-emergence application of pendimethalin 750 g/ha followed by post-emergence application of imazethapyr 100 g/ha was 92.25, 77.09, 74.76, 71.68, respectively as compared to weedy check.

Effect on crop

Weed free treatment recorded the highest dry matter production, pods/plant, seeds/pod, seed and haulm yield, which was statistically at par with pre-emergence application of pendimethalin 750 g/ha + one hand weeding at 30 DAS and two hand weeding at 15 and 30 DAS.

The highest grain and haulm yield was recorded in weed free treatment as 1.42 t/ha and 3.10 t/ha, respectively which was statistically followed by pendimethalin 750 g/ha + hand weeding at 30 DAS with the corresponding grain and haulm yield of 1.38 t/ha and 3.04 t/ha, respectively. The per cent increse in seed yield due to weed free, pre-emergence application of pendimethalin 750 g/ha + hand weeding at 30 DAS, two hand weeding, and pre-emergence application of pendimethalin 750 g/ha *fb* post-emergence application of imazethapyr 100 g/ha was 172.74, 164.11, 153.55 and 136.47, respectively over

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Table 1. Effect of weed management on yield, nutrient uptake and economics in soybean crop

Treatment	Total biomass (t/ha)	Seed yield (t/ha)	Haulm yield (t/ha)	Total N uptake by weeds (kg/ha)	Total P uptake by weeds (kg/ha)	Total N uptake by crop (kg/ha)	Total P uptake by crop (kg/ha)	Net return (x10^3 `/ha)	B:C ratio
Pendimethalin 750 g/ha PE	0.80	0.91	2.08	15.39	2.20	88.23	9.66	15.11	1.80
Metribuzin 350 g/ha PE	0.78	0.83	1.90	15.08	2.14	80.70	8.83	12.52	1.68
Fenoxaprop-p-ethyl 75 g/ha POE	0.76	1.00	2.29	14.61	2.08	97.43	10.62	18.08	1.94
Imazethapyr 100 g/ha POE	0.72	1.04	2.38	13.79	1.96	101.75	11.05	19.26	1.98
Pendimethalin 750 g/ha PE + HW at 30 DAS	0.43	1.38	3.04	8.17	1.18	137.93	15.03	29.51	2.38
Metribuzin 350 g/ha PE + HW at 30 DAS	0.54	1.13	2.57	10.34	1.47	113.88	12.47	21.02	2.00
Pendimethalin 750 g/ha PE + fenoxaprop-p-ethyl POE	0.57	1.18	2.69	10.84	1.55	117.70	12.72	23.27	2.12
Pendimethalin 750 g/ha PE + imazethapyr 100 g/ha POE	0.53	1.23	2.79	10.14	1.44	123.33	13.44	24.70	2.17
Metribuzin 350 g/ha PE + fenoxaprop-p-ethyl 75 g/ha POE	0.56	1.13	2.57	10.84	1.53	112.92	12.20	21.64	2.06
Metribuzin 350 g/ha PE + imazethapyr 100 g/ha POE	0.56	1.18	2.71	10.83	1.53	118.52	12.82	23.43	2.13
One hand weeding at 20 DAS	0.63	1.12	2.54	12.12	1.71	108.52	11.97	21.51	2.08
Two hand weeding at 15 and 30 DAS	0.48	1.32	2.90	9.04	1.28	131.91	14.49	27.24	2.26
Weed free up to 50 days	0.15	1.42	3.10	2.78	0.40	143.78	15.63	26.75	2.04
Weedy check	1.88	0.52	1.36	33.91	4.88	52.32	5.64	2.34	1.13
LSD (P=0.05)	0.11	0.21	0.40	2.18	0.31	18.31	2.12	-	-

PE= Pre-emergence; POE= Post-emergence

weedy check. The result corroborate with the finding of Singh *et al.* (2015).

Nutrient uptake by weeds

All the weed management treatments significantly reduced the uptake of N and P by the weeds compared to weedy check. The minimum removal of total nitrogen (2.78 kg/ha) and phosphorus (0.40 kg/ha) by weeds were observed under weed free treatment which was closely followed by pendimethalin 750 g/ha + hand weeding at 30 DAS and two hand weeding treatment at 15 and 30 DAS (Table 1), while the maximum total removal of nutrient (33.91 kg/ha N and 4.88 kg/ha P) was recorded under weedy check. The uptake of N and P by weeds was estimated as 39.3 and 46.4%, respectively of the total removal (weeds + crop) in weedy check and only 5.59 and 7.28% N and P, respectively under pendimethalin 0.75 kg/ha + hand weeding at 30 DAS treatment and thus, treatment saved 33.7% nitrogen and 39.1% phosphorus over weedy check. The uptake of nitrogen and phosphorus by the crop and weeds could be mainly attributed to the extent of their dry matter production. It is apparent (Table 1) that whenever the removal of nutrients by weeds was more, corresponding uptake by the crops was less or vice-versa. Reduced nutrient uptake by weeds under the influence of different weed control measures have also been reported by Kalhapure *et al.* (2015).

Nutrient uptake by crops

The highest total N and P uptake by the crop (143.8 kg/ha and 15.6 kg/ha, respectively) was recorded under weed free treatment, which was closely followed by pendimethalin 750 g/ha + hand weeding at 30 DAS and two hand weeding treatment at 15 and 30 DAS, which might be ascribed to higher yield with these treatments. Weed free, pre-emergence application of pendimethalin 750 g/ha + hand weeding at 30 DAS, two hand weeding treatment increased N and P uptake by the crop to the tune of 174.8, 163.6, 152.1 and 177.1, 166.5, 156.9%, respectively over weedy check. These results were in close conformity with the finding of Habimana *et al.* (2013). The highest net returns (` 29508/ha) and BC ratio (2.38) were obtained under pre-emergence application of pendimethalin + hand weeding at 30 DAS followed by two hand weeding at 15 and 30 DAS with net return of ` 27244/ha and BC ratio of 2.26.

SUMMARY

On the basis of one-year field experiment at Udaipur during *Kharif* 2014 it was emerged that pre-emergence application of pendimethalin 750 g/ha + hand weeding at 30 DAS recorded the maximum seed yield (1.38 t/ha) along with the highest economic returns in terms of net returns and B: C ratio of ‘ 27244/ha and 2.32, respectively.

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Short communication

Biological activity of red wriggler earthworm using puncture wine weed with cow dung as substrate

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Key words- Biological activity, Earthworm, Vermicomposting, Weeds utilization

About 2,350 years ago Aristotle has said, "Earthworms are intestines of the earth." Vermicomposting is the process of producing organic fertilizer or the vermicompost from bio-degradable materials with earthworms.

A huge amount of plant biomass is available in the form of weeds. Proper utilization of these weeds can improve soil physical condition and environmental quality as well as provide nutrients for plant (Bhardwaj 1995). The recycling, reuse and resource recovery has been considered as one of the best options for waste management programme. It is well documented that earthworm excreta has higher amounts of nutrients than that of the substrates or soil on which the earthworms feed. Moreover, the nutrients are changed to assimilable forms in the gut, that are more rapidly taken up by plants (Gunadi and Edwards 2003)

Carbon and nitrogen content of the organic matter determine the abundance and diversity of earthworm species (Kale and Krishnanmoorthy 1981). By using different weeds as raw material for vermicomposting their order of preference by earthworms can be determined.

There is not much published report available regarding the vermicomposting of weeds. It is in view of this lacuna and for better understanding of the process of vermicomposting, work on the present problem has been selected. This work presents the dynamics of *E. foetida* earthworm populations during vermicomposting of puncture wine weed (*Tribulus terristris*).

Experiment was carried out to study growth and fecundity of earthworm *Eisenia foetida* using puncture wine (*Tribulus terristris*) weed mixed with cowdung as substrate in different weed and cow dung proportions (Table 1). Three hundred gram of feed mixture was taken in plastic containers of 500 g capacity. All the treatments were kept in triplicate and same setup without earthworm were also maintained which served as control. All the treatment containers were left for 15 days prior to experimentation for thermal stabilization and softening of wastes for easy ingestion by the earthworm. The water was sprinkled over the feed mixture on alternate day to hold moisture content of about 60 to 80%. After 15 days, 10 healthy non-clitellated earthworm weighing 150 to 300 mg were selected form stock culture and introduced in each container. To prevent moisture loss the containers were covered with wet gunny begs. All containers were placed in darkness at room temperature. No additional food was added at any stage during the study period.

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Eisenia foetida specimens of the earthworm commonly known as red wrigglers were used in this study. Young, healthy clitellated earthworms or hatchlings (as per requirements) were randomly picked from several different cultures (each containing 500-2000 earthworms) maintained in the department of botany, Sri Guru Nanak PG Khalsa College, Sri Ganganagar, Rajasthan using cow dung as the culturing material

Fresh cow dung (CD) cow dung was procured from 4Z village, Sri Ganganagar, Rajasthan. The main characteristics of CD were: pH :7.73, organic carbon (OC): 362.3 g/kg, total kjeldhal nitrogen (TKN): 6.5 g/kg, total phosphorus (TP): 4.2 g/kg, total potassium (TP): 5.11 g/kg, C:N ratio: 55.65, calcium (Ca): 3.2 g/kg, and C:P ratio: 84.65.

Table 1. Content of weed with cow dung in initial feed mixture

Feed composition	Weed %	Cow dung %
C_1	0	100
C_2	20	80
C_3	40	60
C_4	60	40
C_5	80	20

Growth and fecundity study

Growth and cocoon production in each mixture was recorded weekly for 18 weeks. The feed in the containers was turned out and earthworms and cocoons were separated from the feed by hand sorting, after which they were counted and weighed after washing with water and drying them by paper towels. The worms were weighed without first voiding them, since it has been reported that the gut content would lie around 10% of live weight, where as larger differences are expected in relation to feed (Neuhauser *et al*. 1980). Corrections for gut content were not applied to any of the data in the study. Then all measured earthworm and feed (but not cocoons) were returned to the containers.

At the end of vermicomposting period, earthworms and cocoons were separated and final compost from each container was air dried at room temperature. Homogenized samples of final compost were ground in a stainless steel blend, stored in airtight plastic vials for further chemical analysis.

No mortality was observed in any of the feed mixture in the present experiment. Gunadi and Edwards (2003) have reported the death of *Eisenia foetida* after 2 weeks in fresh cattle solids, although physiochemical properties were suitable for the growth of the earthworms. They attributed the deaths of earthworms to the anaerobic conditions which developed after 2 weeks in fresh cattle solids. In our experiments, all the weed feed mixture was pre-composted for 2 weeks and during this period all the toxic gases produced might have been eliminated. It is established that pre composting is essential to avoid the deaths of the worms.

The change in biomass and cocoon production differed depending on the substrates. The changes in worm biomass for all the feed mixtures over the observation period illustrated (Table 2). The maximum biomass (1146 ± 3.12 mg) after 120 days was observed in 20:80 (weed : cow dung) treatment and minimum biomass (993 ± 5.19 mg) in 100% cow dung. All the compositions showed increase in biomass at all the time periods with respect to control. The increase was linear up to 12 months but after that it showed a decline trend (Fig. 1).

The maximum growth rate of *Eisenia foetida* was registered between the range of 8 ± 0.04/ earthworm/day (in 80:20 treatment) to 10 ± 0.08/ earthworm/day (in 20:80 treatment). The net weight gain by worm was highest in 20:80 treatment (937 ± 7.65 mg/worm) and lowest in 0:100 treatment (777 ± 7.21 mg/worm).

The maximum weight by earthworm was attained in 12th - 14th week in all the treatments. The fastest growth rate was observed in C_2 treatment (10 ± 0.08 mg/worm/day) whereas C_5 treatment supported the least growth (8 ± 0.04 mg/worm/day). Increasing proportion of weed in the feed mixture promoted a decrease in biomass of *Eisenia foetida.* The loss in worm biomass can be attributed to the exhaustion of food. When *Eisenia foetida* received food below a maintained level, it lost weight at a rate which depended upon quantity and nature of ingestible substrates (Neuhauser *et al.* 1980).

The cocoon production of all the studied feed mixtures over the observation period is illustrated in (Fig. 2). Cocoon production started in 6th week in 100% cow dung; in 5th week in other feed mixtures except C_5 treatment (6th week). After 120 days, maximum cocoons (199 ± 1.52) were counted in C_4 treatment and minimum (143 ± 1.40) in C_1 treatment.

The mean number of cocoon production was between 12.0 ± 0.13 (in C_5 treatment) and 17.0 ± 0.05 (in C_3 treatment) cocoons/earthworm for different feed mixtures tested as shown (Table 3).

Cocoon production fluctuated with time. Initially cocoon production rate was high. The range of mean number of cocoons produced per worm per day was 0.34 ± 0.004 in cow dung to 0.57 ± 0.001 in C_4 treatment. The difference between the rates of cocoon production could be related to the biochemical quality of the feeds, which is an important factor in determining the time taken to reach sex maturity and onset of maturity (Edwards 1988, Edwards *et al.* 1998). Feeds which provide

Table 2. Earthworm growth of *Eisenia foetida* in different feed mixtures of cow dung with *Tribulus terristris* weed (mean ± SEm, n=3)

Feed no.	Mean initial wt./worm (mg)	Maximum wt. achieved/worm (mg)	Maximum wt. achieved in	Net wt. gain/worm (mg)	Growth rate/worm/day (mg)
C_1	216 ± 3.96	993 ± 5.19	12th Week	777 ± 7.21	9 ± 0.08
C_2	209 ± 4.77	1146 ± 3.12	13th Week	937 ± 7.65	10 ± 0.08
C_3	216 ± 4.19	1013 ± 5.06	14th Week	797 ± 6.29	8 ± 0.05
C_4	220 ± 2.51	1022 ± 4.35	13th Week	802 ± 4.81	9 ± 0.04
C_5	199 ± 4.39	999 ± 3.01	14th Week	800 ± 4.65	8 ± 0.04

Fig. 1. Growth pattern of *Eisenia foetida* in feed mixture of *Tribulus terristris*

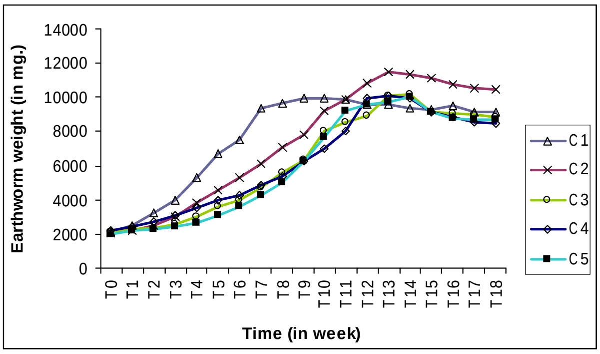

Fig. 2. Cocoon production of *Eisenia foetida* in feed mixture of *Tribulus terristris*

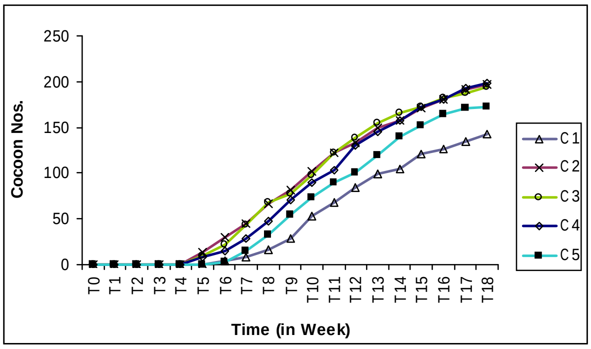

Table 3. Cocoon production by *Eisenia foetida* in different feed mixtures of *Tribulus terristris* weed (mean ± SEm, n=3)

Feed no.	Cocoon production started in	Total nos. of cocoons after 11 weeks	Nos. of cocoons produced/earthworm	Nos. of cocoons produced/earthworm/day
C_1	6th Week	143 ± 1.40	14.3 ± 0.13	0.34 ± 0.004
C_2	5th Week	197 ± 1.40	19.7 ± 0.13	0.56 ± 0.004
C_3	5th Week	194 ± 1.52	19.4 ± 0.04	0.55 ± 0.001
C_4	5th Week	199 ± 1.52	19.9 ± 0.04	0.57 ± 0.001
C_5	6th Week	172 ± 1.52	17.2 ± 0.04	0.41 ± 0.0006

earthworms with sufficient amount of easily metabolizable organic matter and non-assimilated carbohydrates favour growth and reproduction (Edwards 1988). Verma and Kaur (2015) reported that addition of *Chenopodium murale* weed in cow dung not only enhanced the growth of worm but also increased cocoon production

SUMMARY

Fecundity study of earthworm species *Eisenia foetida* during vermicomposting of puncture wine weed (*Tribulus terristris*) mixed with cowdung in different combinations was carried out. It was observed that both weight gain and cocoon production was more when *Tribulus terristris* weed was mixed with pure cowdung. Net biomass gain by earthworm in different feed mixture was in order of $C_2>C_4>C_3>C_5>C_1$ and that of cocoon production of $C_4>C_2>C_3>C_5>C_1$. It indicated that *Tribulus terristris* weed is a good biomass and reproduction supporting medium which can be used effectively for culturing *Eisenia foetida* as well as recycling of weed material for production of vermicompost when mixed with pure cowdung. Therefore, there is a need to divert research activities to expore the potential of different weeds as a raw material for vermicomposting and their utilization and to design a national level policy for their proper utilization.

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