Pak. J. Agri. Sci., Vol. 54(1), 129-134; 2017
ISSN (Print) 0552-9034, ISSN (Online) 2076-0906
DOI: 10.21162/PAKJAS/17.5960
http://www.pakjas.com.pk

COMPARATIVE EFFICACY OF VARIOUS WEED CONTROL MEASURES IN WEED DYNAMICS, YIELD AND PROFITABILITY OF DIRECT SEEDED FINE RICE

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Water and labour scarcity pushes researchers to explore alternate sowing methods for rice like aerobic direct seeding but weed infestation is the major hindrance to adapt this production system. In our study, mechanical, chemical and cultural approaches were employed as weed control measures. Weed dynamics and yield parameters were recorded and economic analysis was performed. All weed control measures significantly reduced the weed density and weed dry weight as compared to control and improved harvest index. Maximum control in total weed density and total weed dry weight was achieved by hoeing followed by chemical control. The order of treatment groups in decreasing total density, total weed dry matter production and increment in harvest index was as cultural, chemical and mechanical. However, substantially highest net returns (PKR 44,049/) and highest benefit cost ratio (BCR) (1.53) were obtained by post emergence application of Penuxsulam at the rate of 15 g a.i ha^{-1} followed by hoeing. Inter-culture, mulching technique and *Sesbania drummondi* intercropping scored 1.19, 1.13 and 1.21 BCR, respectively. Thus, hoeing with hoe (25 and 45 days after sowing) and post emergence application of Penoxsulamat the rate of 15 g a.i ha^{-1} were most effective, profitable and economical weed control options.

Keywords: Direct seeded rice, weed infestation, chemical control, hoeing, inter-culture, mulching.

INTRODUCTION

Rice (*Oryza sativa* L.) is the world major staple crop and is critically helpful for global food security (Maclean *et al*., 2002). It feeds more than half of the world population. Its importance lies in fact that 114 countries are growing rice in world and Asian farmers contribute 90% of total produce (FAO, 2011). In Pakistan, rice crop is grown on 2.9 mha with production of 7.0 million tons. Fine grain rice branded as Basmati; brings handsome international price and contributes a lot in foreign exchange. It contributes 3.2% in agricultural value addition and shares 0.7% in GDP (Government of Pakistan, 2015).

Agriculture covers 70% of the world's water consumption (IWMI, 2007) which is increasing every moment to feed the growing population. Tuong and Bouman (2003) have predicted that 20% of the Asian transplanted rice will experience severe water shortage up to 2025. Water scarcity is an annihilating threat to sustainability of transplanted rice (Saqib *et al.,* 2015). But many of the rice growing countries of Asia including Pakistan are still practicing traditional rice cultivation (Ehsanullah *et al.,* 2007) which requires high delta of water and causing poor edaphic physical factors by reducing water percolation rate and soil water movement (Tripathi *et al.,* 2003). Under the circumference of all these conditions, conventional flooded rice cultivation is losing its social, economic value, acceptability and sustainability (Bhushan *et al.,* 2007). So currently some advances; alternate wetting and drying, raised bed sowing and direct seeded aerobic rice have been made for rice cultivation (Saqib *et al.,* 2015). Direct seeding of rice (DSR) requires less water and labour as compared to flooded rice (Weerakoon *et al.,* 2011). But the only drawback of DSR is weed infestation which substantially reduces the yield potential (Muhammad *et al.,* 2016); as weeds are notorious competitor of rice and major constraint in adaptation of direct seeding (Saqib *et al.,* 2015). Weeds nurture comparatively with impressive growth in DSR compared to flooded rice system and sometimes results into complete crop failure (Phoung *et al.,* 2005).

A lot of research has been conducted on weeds control in DSR in world. Some investigators reported chemical control is best option for weed control (Adigun *et al.,* 2005; Mahajan *et al.,* 2009) while, Laxminarayan and Mishra (2001) reported manual weeding gave considerably higher weed control over other methods but is laborious on large scale. Currently, all researchers are trying to identify best weed control method in DSR without paying attention to economic efficiency of any weed control option. In aerobic rice culture, weed control options might be chemical control with pre emergence herbicides like Pendimethalin and post emergence herbicides like Penoxsulam, cultural (mulching with crop residues and manual weeding), biological (cover cropping/intercropping with *Sesbania drummondi*), mechanical (interculture with cultivator) and integrated management. Cultural weed control via manual weeding or hoeing with an instrument is very common method among small farmers (Chikoye *et al.,* 2004). Hussain *et al.* (2008) manifested in a DSR study that manual weeding resulted in net return of PKR73575/- and 98.8% weed control over control plot. Mulching is another cultural approach that significantly reduces weeds performance and their germination; however, this practice is less practiced among farmers that might be due to less awareness. Chemical control involves application of various herbicides as pre and post emergence. It is cheaper, effective, and easy, and gave better control (Chikoye *et al.,* 2004). Chemical weed control with Pretilachlor caused noticeably higher yield and benefit cost ratio (Islam *et al.,* 2000); however, judicious application of herbicides reduces weed control cost, labor cost and improves yield.

As DSR is becoming socially accepted and rice production is considered as a business, aimed for profit maximization and increased livelihood among farmers. Therefore, there is dire need to compare and compute profitability of different weed control measures that can be employed for better weed control in DSR. The present research was conducted to evaluate most profitable weed control option for profit maximization.

MATERIALS AND METHODS

***Site description*:** A field study was conducted at Agronomic Research Area, University of Agriculture Faisalabad, Pakistan (31.25° N, 73.09° E, and 184 m a.s.l.). The climate of Faisalabad is semi-arid with 200 mm. Soil status was medium alkaline with Electrical Conductivity (EC) 0.43 dSm^{-1}. The pH of the soil was measured in a (1:5) suspension of soil and $H_2O$with the help of digital pH meter, model SP-34 Suntex. EC was determined by the method of Rhoades (1996).

***Application of weed control treatments*:** Experiment was laid out in randomized complete block design (RCBD) with three replications. Fine rice variety "Super Basmati" was used as an experiment material. There were seven weed control treatments grouped into four major groups as weedy check**:** no weed control measure; mechanical control: hoeing with hoe at 25 and 45 days after sowing (DAS) and inter-culture with tine cultivator (15 and 25 DAS). Tine cultivator is manually drawn instrument with tines used for inter-row weeding, Chemical control: Stomp 330 EC (Pendimethalin) at the rate of 1137 g a.i ha^{-1} as pre-emergence and Ryzelon 40 SC (Penoxsulam) at the rate of 15 g a.i ha^{-1} 15 DAS as post emergence. Both herbicides were applied with Knapsack hand sprayer fitted with T-jet nozzle using 300 L ha^{-1}; cultural control:mulching with wheat straw at the rate of 4 t ha^{-1}between rice rows after sowing and Sesbania intercropping between rice rows and was incorporated in soil after 25 DAS of Sesbania with spade.

***Crop husbandry*:** For fine seedbed, four ploughings followed by planking were given by tractor driven cultivator. Seed was hydro-primed for 10 hours and then surface dried near to their original weight followed by the treatment with fungicide Thiophanate methyl at the rate of 2 g kg^{-1}. Seeds were drilled with single row hand drill with spacing 25 cm using seed rate of 75 kg ha^{-1}. Sesbania was intercropped using seed rate of 25 kg ha^{-1}. Recommended fertilizer doses for DSR rice were applied (N @ 125 kg ha^{-1}, P @ 75 kg ha^{-1}, K@ 65 kg ha^{-1}). Field was regularly visited for crop appraisal regarding irrigation supply. Irrigation was stopped one week before harvesting when symptoms of physiological maturity appeared. Each plot was harvested manually when panicles were ripened fully at 23% approximate moisture level, and then harvesting was done manually.

***Data collection*:** A quadrate measuring 1 m x 1 m was randomly placed at two sites in each experimental plot to record total weed density m^{-2} at 60 DAS. For computing weed dry weight, counted weeds from each respective sample of 1 m^2, were harvested and exposed to sun for drying first and then oven dried at 70°C until constant weight was attained. After harvesting and threshing, clean rough seed were air dried and then weighed using electric balance. Kernel weight was expressed in t ha^{-1}, while, biological yield was determined before threshing which included kernel and straw yield and was expressed in t ha^{-1}. Harvest index (HI) was computed by following formula HI (%) = (Kernel yield/Biological yield) × 100.

***Economic analysis*:** Economic analysis of each weed control measure was calculated by partial farm budget (Okoruwa *et al.,* 2005). Prevailing market price, labour charges and harvesting and threshing charges were used to calculate revenue of paddy yield from each treatment. Revenue was computed by multiplying paddy yield with market price of paddy yield: Revenue=YP × PP (where, Y= paddy yield in kg ha^{-1}; PP=Price of paddy). The net income was determined by subtracting cost of production from the grass income: Profit (net revenue) = Total cost of production - gross income. BCR for each weed control practice was calculated by dividing gross income on total cost: BCR = Gross income/Total cost of production.

***Statistical analysis*:** The recorded data was statistically analysed using Fisher's analysis of variances technique while LSD test at 0.05 probability level was applied to compare treatment means (Steel *et al.,* 1997).

RESULTS

Development of diverse weed flora is salient feature of direct seeding of rice and loss due weed competition can be measured by weed density and dry matter attainment. Weed flora at experimental site was consisted of purple nut sedge (*Cyprus rotundus*), jungle rice (*Echino chloacolonum*), barnyard grass (*Echino chloacrussgalli*), bitter weed (*Eclipta alba*), Eligator weed (*Alternanthera philoxeroides*) and Crowfoot grass (*Dactyloctenium aegyptium*). All weed control measures significantly reduced the weed flora development and performance over control. Total weed density (113.18 m^{-2}) and total weed dry weight (114.27 g) were calculated from control plot. From weed control treatments, maximum weed suppression (90.7%) and reduction in total weed dry matter (73.6%) was observed by hoeing with hoe which was statistically at par with Penoxsula m at the rate of 15 g ha^{-1} having 89.0% weed suppression and 71.8% weed dry weight reduction. This was followed by sesbania intercropping which reduced weed density and dry weight by 73.1% and 70.3%. Furthermore, interculture with tine cultivator scored weed suppression by 27.6% and dry matter accumulation by 36.9% and result of dry matter accumulation was statistically at par with Pendimethalin at the rate of 1137 g ha^{-1} with 40.9% reduction (Table 1).

It is apparent from data that all weed control strategies substantially affected the kernel yield. Twice hoeing with hoe at 25 and 45 days after sowing yielded maximum kernel yield (3.35 t ha^{-1}) and biological yield (15.30 t ha^{-1}) which was statistically at par with post emergence application of Penoxsulam at the rate of 15 g ha^{-1}. This was followed by Wheat straw mulching at the rate of 4 t ha^{-1}. Least kernel yield (1.93 t ha^{-1}) and biological yield (11.77 t ha^{-1}) was achieved from control plot. Pre-emergence application of Pendimethalin at the rate of 1137 g ha^{-1} gave comparatively less kernel yield (2.65 t ha^{-1}) and biological yield (14.40 t ha^{-1}) than post-emergence application of Penoxsulam at the rate of 15 g ha^{-1}. Interculture with tine cultivator was surpassed by twice hoeing with hoe 25 and 45 DAS. The results showed the significant effect of weed control strategies in improving harvest index over control. Twice hoeing with hoe 25 and 45 DAS gave maximum harvest index of 21.1% and was statistically similar to post emergence application of Penoxsulam at the rate of 15 g ha^{-1}.Sesbania intercropping gave 19.2% harvest index which was statistically at par with Wheat straw mulching at the rate of 4 t ha^{-1}. Least harvest index of 17.71% from weed control treatments was offered by inter-culture with tine cultivator and control gave 16.4% harvest index (Table 1).

A perusal of data revealed that Penoxsulam at the rate of 15 g ha^{-1} gave the highest BCR of 1.53 with the maximum net returns of PKR 44049 ha^{-1} following by Hoeing which showed BCR 1.47 with the net returns of PKR 42271. Wheat

Table 1. Influence of different weed control measures on the weed dynamics and yield of direct seeded aerobic fine rice.

Weed control measures	Weed density (m^{-2})	Weed dry weight (g m^{-2})	Kernel Yield (t ha^{-1})	Biological yield (t ha^{-1})	Harvest index (%)
Weedy check	113.18 a	114.27 a	1.93 e	11.77 e	16.43 e
Hoeing with hoe	10.50 e	30.15 d	3.35 a	15.30 a	21.90 a
Interculture with tine cultivator	82.02 b	72.13 b	2.40 d	13.55 c	17.71 d
Pendimethalin @ 1137 g ha^{-1}	52.72 c	67.56 b	2.65 b c	14.40 b	18.40 cd
Penoxsulam @ 15 g ha^{-1}	12.43 e	32.21 b	3.25 a	15.10 a	21.52 a
Wheat straw mulching @ 4 t ha^{-1}	52.90 c	49.39 c	2.73 b	14.24 b	19.22 bc
Sesbania intercropping	30.50 d	33.93 d	2.50 cd	12.80 d	19.92 b
LSD value	4.7851	6.7223	0.1783	0.4030	1.2367

Means in column having different letters differ significantly at $p < 0.05$.

Table 2. Economic analysis of weed control treatments

Weed control measures	Grain yield (t ha^{-1})	Total revenue (PKRha^{-1})	Gross income (PKR ha^{-1})	Total Cost (PKRha^{-1})	Net returns (PKRha^{-1})	BCR
Weedy check	1.93	69963	78318	77926	392	1.01
Hoeing with hoe	3.35	121438	131595	89324	42271	1.47
Interculture with tine cultivator	2.40	87000	96478	81130	15348	1.19
Pendimethalin @ 1137 g ha^{-1}	2.65	96063	106050	82536	23514	1.28
Penoxsulam @ 15 g ha^{-1}	3.25	117813	127885	83836	44049	1.53
Wheat straw mulching @ 4 t ha^{-1}	2.73	98963	108738	96326	12411	1.13
Sesbania intercropping	2.50	90625	99380	82118	17263	1.21

BCR = Benefit cost ratio, Paddy price PKR / 40 kg= 1450/-

straw mulching is good technique for weed suppression while it scored least BCR 1.13 with the net returns of PKR 12411. Inter-culture with tine cultivator gave rise to BCR 1.19 with the net returns of PKR 15348. In terms of total cost, Wheat straw mulching bearded maximum cost of PKR 96326 (Table 2).

DISCUSSION

Hoeing with hoe twice at 15 and 45 DAS suppressed maximum weeds as shown by least total weed density and total weed dry weight. These results are in agreement with the result of Parasad *et al.* (2001) who stated that hoeing was economical among weed control methods. This might be attributed to soil stirring effect of hoeing. Furthermore, more weeds might be uprooted and provide more weed completion free period. Contradictions are there on employing hoeing due to intensive labour requirement to control weed in direct seeded rice, though it gave higher reduction in total weed dry weight in our study (Table 1). Mulching with wheat straw reduced weed infestation by 53% over control and less reduction by this method might be a result of improper management or inappropriate method of straw application. This might be due to rigorous weed crop competition. However, weed control treated plots significantly reduced weed dynamics and might be attributed to prevalence of less favourable environment. Lower the dry weight dry matter production, lower will be the exploitation of natural resources. However, this is not in case of weeds, aggressive behaviour of weeds can be determined by dry matter production. There must be low weed dry matter production in order to sustain production level.

Control plot where no weed control treatments were performed, negatively influenced kernel yield, biological yield and harvest index. Increase in kernel and biological yield over control might be due to improvement in crop growth, less weed crop competition period as a result of implemented treatments (Zhang *et al.,* 2008). Higher paddy yield was recorded in hoeing and might be due to less weed infestation. Harvest index, which is the ultimate objective of any production system, depends on the efficacy of that system. In DSR, weeds have direct impact in reducing harvest index; though adoption of good weed control practices may enhance it. Harvest index improvement might be attributed to have less weed competition, development of high kernel yield (Tindal *et al.,* 2005; Farooq *et al.,* 2011). Furthermore, attainment of high yield from hoeing might be due to increased availability of nutrients as a result of soil stirring during hoeing with hoe (Arif *et al.,* 2004). The yield difference among herbicides was 0.25 t ha^{-1}. The pre-emergence application of Pendimethalin gave less yield and might be as a result of some phytotoxic effect of Pendimethaline on rice plant (Smith, 2004), it may affect germination or seedling emergence of rice or may have residual effect thus reducing the growth and development of rice, contrarily, post emergence application of Penoxsulam provided some time for seedling development of rice and its latter application only declined weed growth. As weed free environment improves rice kernel quality (Farooq *et al.,* 2011).

Higher net income due to post emergence application of Penoxsulam and twice hoeing with hoe ascribed to higher paddy and higher straw yield as they produced better weed free environment and may provide better growing conditions for rice resulting in production of more number of tillers, higher grain weight and biological yield. The less net income from sesbania intercropping (PKR 17263/-) might be ascribed to inter-specific competition between *Sesbania drummondi* and rice, thus interfering with growth and development of rice. Mulching is most appropriate technique for weed suppression while, it gave least net return of PKR 12,411. Attaining least net return referred to high price of wheat straw thus increasing cost of this technique and making this option economically not beneficial. However, several studies are contradictory to our findings, who reported that manual weeding hoeing was economically not viable as labour charges pertained to be high, however chemical control had significant weed control (Akbar *et al.,* 2011; Khaliq *et al.,* 2012). This affirms the report of Adigun and Lagoke (2003) that hoeing is expensive and gave less BCR, while herbicide advantage included instant weed control and attributed with higher BCR over other treatments. These results are in confirmatory with Olabode *et al.* (2009), who reported that mulching gave less net return, as it is expensive with high cost. Several studies contradicted our findings and highlighted that chemical control gave more weed control in term of less price (cost) than manually controlled weed option (Akbar *et al.,* 2011; Gopal *et al.,* 2010). However, in our study, experimental data elicited that though hoeing with hoe has high cost of employment, but this high cost has been compensated with high paddy yield over all other treatments.

Conclusion: All weed control methods showed effective results in weed control over control. Overall cultural weed control (twice hoeing with hoe at 15 and 45 DAS) followed by chemical control using Penoxsulam (post emergence) showed maximum reduction in total weed density and total weed dry weight. However, the economic analysis revealed that chemical control using post emergence herbicide was most efficient in terms of net returns and BCR. It was followed by manual hoeing and may be employed if there is no shortage of labour because it is environment friendly or integrated approach of both is suggested.

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