Research Article

ECOLOGICAL WEED MANAGEMENT PRACTICES AND SEED BED PREPARATION OPTIMIZED THE YIELD OF DRY DIRECT SEEDED RICE IN SUB-HUMID CONDITION OF CHITWAN, NEPAL

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ABSTRACT

The weeds are a major constraint of dry-direct seeded rice (DDSR) due to change in establishment methods and shifting weed flora towards competitive grasses and sedges. For optimizing the yield of DDSR through environmental friendly weed management practices, two field experiments were conducted during the monsoon season of 2014 on Chitwan, Nepal. First experiment was done using a strip plot design to find the optimum seed rate and killing date of *sesbania* under rice-*sesbania* co-culture whereas the second experiment was done by using a split plot to observe the efficiency of stale seed bed for weed control and to identify the best integrated weed management practice. The optimum seed rate of *sesbania* was 102 kg ha^{-1} and killing dates was 32 days. The *sesbania* co-culture with 100 kg ha^{-1} when killed at 28 days had produced significantly higher grain yield than sole Bispyribac Na application, and only 4.79% yield was loss than farmers' practice of two hand weeding. In contrary to weed free, Pendimethalin followed by Bispyribac Na application and Pendimethalin followed by 2,4-D application produced statistically similar yield followed by *sesbania* co-culture with 100 kg seeds and killing at 28 days. During the monsoon rice, the effectiveness of stale seed bed was not much greater (0.37%) than the normal seed bed.

Key words: hand weeding, *sesbania* co-culture, stale seed bed, weed index

INTRODUCTION

The national average yields of rice in Nepal (3.17 t ha^{-1}) is far below the attainable yield of 5.00 t ha^{-1} (FAO, 2014; Dey, and Hossain, 1995) consisting the yield gap of 1.83 (57.73%). Conventionally rice is cultivated by transplanting of 20-30 days seedlings after puddling. Puddling have advantages of reducing weed population (Surendra, Sharma, Rajendra, Singh, & Prasad, 2001), enhancing nutrient uptake by creating anaerobic condition, higher water use efficiency by reducing the evaporation and percolation loss, facilitate transplanting and easy seedling establishment (Sanchez, 1973). But it adversely affects soil physical properties by dismantling soil aggregates, reducing permeability in sub-surface layers (Sharma,Ladha, & bhushan, 2003), forming hard pans at shallow depths which hinders the root development of non-rice crops grown in rice based cropping system and greater emission of methane gas in atmosphere contributing global warming (Tripathi, Sharma, & Singh, 2005) and urged for substitutes.

Dry-DSR gaining popularity regarding its high water use, labor use and energy use efficiencies

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(Kumar, & Ladha, 2011). Instead of the conventional transplanting, Dry-DSR reduces the water (12-35%) and labour demand (up to 40%) which ultimately decreases the cost of production (Mann, Ahmad, Hassan, & Baloch., 2007). But in most of the cases farmers harvest lower yield from Dry-DSR in different production zones due to uneven or poor crop emergence (Rickman et al., 2001); inadequate weed control (Kumar et al., 2008); higher spikelet sterility than in puddled transplanting (Bhushan, Ladha, Gupta, Singh, Tirol-Padre, Saharawat, Gathala, & Pathak, 2007); higher crop lodging, especially in broadcasting (Rickman, Pyseth, Bunna, & Sinath, 2001) and insufficient knowledge of water and micro-nutrient management (Humphreys, Kukal, Christen, Hira, Singh, Yadav, & Sharma, 2010).

Changes in rice establishment method as well as water, tillage and weed management practices from CT-TPR to Dry-DSR lead can drastic change in weed composition, density and diversity (Singh, Bharadwaj, Thakur, Pachauri, Singh, & Mishra, 2009). In addition, adopting Dry-DSR may result in weed flora shifts toward more difficult to control and competitive grasses and sedges. Further weeds are more problematic in DSR-DSR than in puddled transplanting because emerging Dry-DSR seedlings are less competitive with synchronously emerging weeds and the initial flush of weeds is not controlled by flooding (Kumar et al., 2008). Thus the weeds are a major constraint to the success of Dry-DSR (Rao, Johnson, Sivaprasad, Ladha, & Mortimer, 2007; Singh, Bhushan, Ladha, Gupta, Rao, & Siva, 2006). Research has shown that, in the absence of effective weed control options, yield losses are greater in Dry-DSR than in CT-TPR (Baltazar, & De Datta, 1992). The present study was initiated in developing effective, ecologically and economically viable medium- to long-term sustainable weed control strategies under dry-DSR.

MATERIALS AND METHODS

Experimental site

Two separate field experiments were conducted in the Agronomy Farm of Agriculture and Forestry University (AFU), Rampur, Chitwan representing inner terai region of Nepal during the rainy season of 2014 (June to November). The area has a sub-tropical climate highly influenced by the southern monsoon.

Physio-chemical properties of experimental soil

Soil samples were randomly taken from different spots from 0 – 15 cm depth using tube auger and made composite to record the initial soil physico-chemical properties of the experimental site. The total nitrogen was determined by Kjeldhal distillation unit, available phosphorus by modified Olsen's method by using spectrophotometer and available potassium by ammonium acetate method. Organic matter was determined by Walkey and Black method, pH (1:1 soil: water suspensions) by Beckman Glass Electrode pH meter and soil texture by hydrometer method. Soil pH was slightly acidic (5.20) in reaction with organic carbon (1.88%) and total nitrogen (0.16%). Available P was also in medium rating (46.62 kg ha^{-1}), while that of K was low (82.80 kg ha^{-1}). Soil texture was sandy loam with 63.10% sand, 28.00% silt and 8.90% clay.

Climatic condition during experimentation

The metrological data for cropping season was recorded from the metrological station of

National Maize Research Program (NMRP), Rampur, Chitwan, Nepal near by the research site (Figure 1). The total rainfall of 2406.86 mm was received during the entire period of experimentation, whereas 1953.66 mm of rainfall was recorded in the rice growing period. The highest rainfall was recorded during August (895.40 mm). First three months of rice growing period, the crop received more or less uniformly distributed rainfall with a monthly average not less than 400 mm. The maximum temperature during the experimental period ranged from 24.20^{0}C to 38.20^{0}C during experimentation period. It was the highest during July and the lowest during October. Similarly, the minimum temperature during cropping period ranges from 20.00^{0}C to 30.00^{0}C. It was the highest during June and the lowest during October.

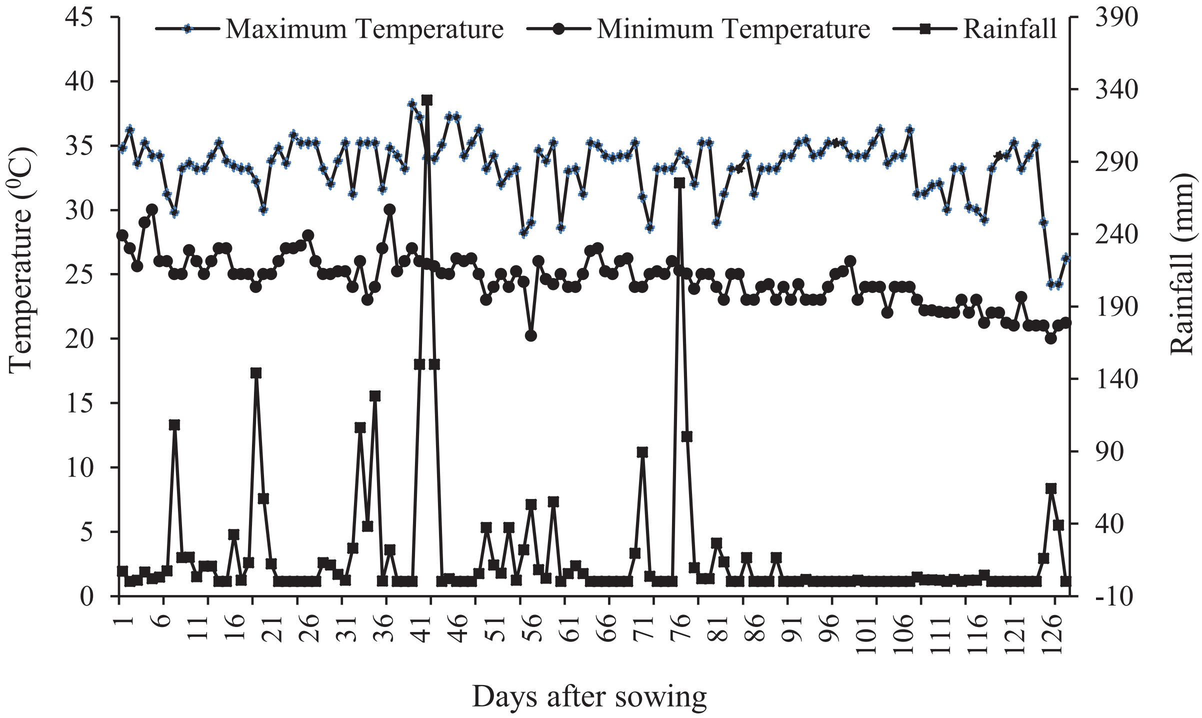

Figure 1. Weather condition during the experimentation period at Rampur, Chitwan, Nepal from 15 May to 20 October 2014

Experimental details

Two different experiments of weed management under dry-DSR were conducted in Agronomy Research Block of Agriculture and Forestry University during rainy season of 2014 as given below:

Experiment I (Sesbania rice co-culture experiment): The experiment was conducted in 3 x 4 strip plot design with three replications. Three levels of seed rate of *Sesbania* (60, 80 and 100 kg ha^{-1}) was laid out as the horizontal factor, whereas four killing dates of *Sesbania* (21, 28, 35 and 42 DAS) as the vertical factor. Four control plots namely, weed free (maintained by the hand removal of weeds at 10 days interval); farmers' practice (2 hand weeding at 28 and 42 DAS); sole post emergence application of Bispyribac Na 25 g a.i. at 25 DAS and weedy check (no weed control) were also managed a side of the experiment with three replications. The rice hybrid US 312 was planted with the fertilizer dose of 150: 80:60 kg N, P_2O_5 and K_2O ha^{-1} respectively.

Experiment II (Seed bed preparation and integrated weed management practice*)*: The experiment was conducted in 2 x 6 split plot design with four replications. Seed bed preparation (stale seed bed and normal seed bed) was laid out as main plot factor whereas different module of integrated weed management practices (pre-emergence application of Pendimethalin 1 kg a.i. ha^{-1} + post emergence application of 2,4,-D 500 g a.i. at 25 DAS; post emergence application of Bispyribac Na 25 g a.i. ha^{-1} at 25 DAS; pre-emergence application of Pendimethalin 1 kg a.i. ha^{-1} + post emergence application of Bispyribac Na 25 g a.i. at 25 DAS; *Sesbania* rice co-culture with *Sesbania* seed of 80 kg ha^{-1} and killing at 30 DAS followed by hand weeding; weed free and weedy check) as the sub plot factor. Normal seed bed was maintained by one deep plowing followed by 3 light plowing and planking and stale seed bed was maintained by one deep plowing followed by 3 light plowing and planking and irrigated the field and left for one week for initial flushes of weeds and Glyphosate 47% SL (3 ml $liter^{-1}$ of water) was applied to the appeared weeds before the sowing of crops. The popular hybrid variety Radha 4 was planted with the fertilizer dose of 120: 60:40 kg N, P_2O_5 and K_2O ha^{-1} respectively.

Plot size, layout and crop sowing

The size of individual plot was 4 m x 5 m (20 m^2) from with experiments. Bund of 1 m width separated the two main plots and 0.5 m distance between each sub plots was maintained for each experiment. Each replication was separated by 1 m bund. Rice was sown manually continuously in line with a row spacing of 20 cm with a seed of 45 kg ha^{-1}. Central ten rows were treated as net plot rows for harvesting.

Herbicide application and crop management practices

Before sowing seeds, glyphosate 47 SL @ 2.5 ml lit^{-1} was applied on the field. One deep plowing followed by 3 light plowing was done followed by planking. Rice was sown with 45 kg ha^{-1} seed rate. The *Sesbania* in rice-*Sesbania* co-culture was killed by the application of 2,4-D ethyl ester at 750 g a.i. ha^{-1}. Full amount of P and K and $1/3^{rd}$ N was applied as basal application and incorporated to the soil. Remaining $2/3^{rd}$ nitrogen were applied at 28 DAS and 45 DAS in two equal splits. The crop from the net plot area was harvested manually at physiological maturity with the help of sickles. Harvested plants were left *in-situ* in the field for 3-4 days for sun drying. Threshing was done by simple mechanical thresher, cleaned by winnowing and weighted at their exact moisture.

Measurements

To measure total above-ground biomass and grain yields the central fifteen rows of each plot were harvested. Plant parameters collected were grain yield, above-ground total biomass, and harvest index. Additionally yield components, number of effective tillers per square meter, number of grains per panicle, sterility percentage, and thousand grains weight were also collected. From the two quadrate of 1 m^2 number of panicle bearing tillers were recorded. Twenty panicles were randomly selected from each plot to count the average number of grains per panicle and sterility percentage. A sample of 500 grains was weighed from each plots to derive thousand grain weights. Seed moisture content mass was measured using a Farmcomp Grain moisture tester (Wile 55). Total biomass (dry matter basis) and grain yields (adjusted to a moisture content of 14%), which were recorded on plot basis, were converted to kg ha^{-1} for statistical analysis.

Statistical procedure

Dependent variables were subjected to analysis of variance using GenStat in strip plot design for experiment I and split plot design for experiment II. All the recorded data were subjected to analysis of variance and Duncan's multiple range test (DMRT) for mean separations. Treatments differences were considered statistically significant at 0.05 levels of significance. Correlation and regression analysis was run between selected parameters. And SPSS was used for the regression analysis and MS Excel was used for the graphical analysis.

RESULTS

Performance of chemical and *Sesbania* rice co-culture over farmers' practice

The performance of popular chemical used to manage weed and *Sesbania* co culture over the farmer practice was summarized on Table 1. The effective tillers per square meter of *Sesbania* co-culture is significantly lower than the weed free but significantly higher than other practices. The grains per panicle, thousand grain weight and sterility percentage of *Sesbania* co-culture were higher than other treatments, but significant only than that of weedy check. The *Sesbania* co-culture had produced significantly higher grain yield than the sole application of Bispyribac Na 25 g a.i. ha^{-1} and weedy check. The co-culture treatment had 4.79% higher yield as compared to the farmers' practice but not significant. The straw yield of rice under *Sesbania* co-culture was comparable to other treatments except weedy check as it had the lowest straw yield. There was not difference in result of harvest index.

Table 1: Yield and yield component influenced by different weed management practices at AFU Agronomy Farm, Rampur, Chitwan, Nepal, 2014

Treatment	Effective tillers per m^2	Grains per panicle	Thousand grain weight (g)	Sterility (%)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	HI
Farmer's practice	250.67^{ab}	101.64^{a}	19.05^{a}	15.93^{ab}	4112.16^{a}	6502.44^{a}	0.35
Bispyribac Na 25 g a.i.ha^{-1}	181.67^{c}	100.73^{a}	18.89^{a}	12.98^{b}	2929.60^{b}	5997.76^{a}	0.27
Sesbania co-culture	223.67^{b}	121.77^{a}	18.72^{a}	13.03^{b}	4309.13^{a}	5498.59^{a}	0.40
Weed free	286.00^{a}	110.37^{a}	18.14^{ab}	9.65^{b}	4823.27^{a}	6764.17^{a}	0.37
Weedy check	40.67^{d}	62.03^{b}	16.93^{b}	20.69^{a}	440.96^{c}	999.47^{b}	0.76
SEm (±)	12.94	6.94	0.45	2.05	282.20	534.6	0.29
LSD (=0.05)	40.79	21.86	1.41	6.45	889.2	1684.6	ns
CV, %	11.40	12.10	4.20	24.50	14.70	18	118.90
Grand mean	196.53	99.31	24.57	14.45	3323.02	5152.49	0.43

Note: Farmers' practice, two hand weeding at 24 and 40 DAS; *Sesbania* co-culture, seed rate of *Sesbania* with 100 kg ha^{-1} and killing at 28 days after sowing. Treatment means followed by common letter(s) within column are not significantly different among each other based on DMRT at 0.05 level of significance.

Performance of stale seed bed and weed management practices

Effective tillers per square meter and thousand grains weight were significantly influenced by seed bed preparation practice, but number of grains per panicle, sterility percentage, straw and grain yields and harvest index were statistically similar on stale seed and normal seed bed (Table 2). Stale bed produced significantly higher number of effective tillers per square meter and thousand grain weight than normal bed. Stale seed bed although produced relatively higher number of grains per panicle, grain and straw yields, lower sterility and higher harvest index than under normal seed bed.

The effect of weed management practices on yield and yield components were found significant (Table 2). Effective tillers per square meter were the highest in weed free plot which was statistically at par with pre-emergence application of Pendimethalin + either post emergence application of Bispyribac Na or 2,4-D, applied plots. Among the weeds management practices, the lowest number of effective tillers per square meter was observed in *Sesbania* co-culture followed by one hand weeding which is however significantly higher than weedy checks. The highest number of grains per panicle was observed in pre-emergence application of Pendimethalin + post emergence application of 2, 4-D, and it was statistically similar to *Sesbania* co-culture followed by one hand weeding. Weed free, post emergence application of Bispyribac Na either sole or followed by pre emergence application of Pendimethalin produced similar number of grains per panicle which is significantly lower than above mentioned treatments but significantly higher than weedy check. Thousand grain weight was lowered in treatment with pre-emergence application of Pendimethalin + post emergence application of Bispyribac Na. Among the treatments, weedy check resulted significantly higher sterility percent which is similar to *Sesbania* co-culture followed by one hand weeding and all other treatments were significantly lowered than weedy check and *Sesbania* co-culture followed by one hand weeding, however, statistically similar to each other.

Table 2: Yield attributes and yield influenced by seed bed preparation methods and different weed management practices at AFU Agronomy Farm, Rampur, Chitwan, Nepal, 2014

Treatments	Effective tillers per m^{-2}	Grains per panicle	Thousand grains weight (g)	Sterility (%)	Grain yield (tha^{-1})	Straw yield (tha^{-1})	Harvest index (%)
Seedbed preparation methods							
Stale seed bed	262.40^{a}	71.75	24.77^{a}	15.18	3293.00	4189.00	37.49
Normal seed bed	237.10^{b}	70.55	24.40^{b}	14.12	3281.00	3857.00	40.11
SEm (±)	10.56	10.01	0.11	1.06	260.40	364.20	2.00
LSD (=0.05)	23.76	22.53^{ns}	0.23	2.37^{ns}	586.10^{ns}	819.50^{ns}	4.60^{ns}
CV, %	4.20	14.10	0.40	7.20	7.90	9.10	5.30
Weed management practices							
Pendimethalin +2,4-D	285.90^{ac}	90.90^{a}	24.56^{ab}	12.70^{b}	3862.00^{ab}	4695.00^{ab}	41.48^{b}
Bispyribac Na	277.50^{c}	68.38^{b}	24.41^{ab}	13.85^{b}	3356.00^{b}	4590.00^{b}	38.39^{b}
Pendimethalin + Bispyribac Na	323.00^{ab}	70.15^{b}	24.11^{b}	12.85^{b}	4157.00^{a}	5265.00^{a}	40.66^{b}

Sesbania co-culture + one HW	235.90[d]	84.44[a]	24.60[ab]	16.58[a]	3356.00[b]	3587.00[c]	48.16[a]
Weedy check	51.6[e]	43.50[c]	24.97[a]	18.36[a]	319.00[d]	849.00[d]	23.05[c]
Weed free check	324.5[a]	69.53[b]	24.83[ab]	13.56[b]	4171.00[a]	5150.00[ab]	41.08[b]
SEm (±)	36.33	10.87	0.69	2.57	478.30	547.50	4.14
LSD (=0.05)	37.10	11.10	0.71	2.63	488.40	559.10	4.23
CV, %	14.50	15.30	2.80	17.60	14.60	13.60	10.70
Grand Mean	249.70	71.15	24.581	14.65	3287.00	4023.00	38.80

Note: ns, non significant; HW, hand weeding. Treatment means followed by common letter(s) within column are not significantly different among each other based on DMRT at 0.05 level of significance.

Weed free and pre-emergence application of Pendimethalin + post emergence application of Bispyribac Na plots produced significantly higher grain and straw yield than sole Bispyribac Na applied plots. Grain yield was the highest in weed free plots but was statistically at par with pre-emergence application of Pendimethalin either with post emergence application of Bispyribac Na plots or 2,4-D plots, however, straw yield was observed highest in pre-emergence application of Pendimethalin + post emergence application of Bispyribac Na plots and was significantly higher than sole application of Bispyribac Na (Table 2). Higher grain yields in weed free and pre-emergence application of Pendimethalin + post emergence application of Bispyribac Na is attributed by its higher number of effective tillers per square meter, number of grains per panicle, thousand grains weight and lower sterility percent. *Sesbania* co-culture followed by one hand weeding produced significantly higher harvest index

Performance of *Sesbania* co-culture

The effect of three different seed rates of *Sesbania* (60, 80 and 100 kg ha^{-1}) and four different killing dates of *Sesbania* (21, 28, 35 and 42 DAS) under *Sesbania* rice co-culture on yield and yield components of rice are listed in Table 3. Regarding the yield attributes of rice seed rate of *Sesbania* had significant effect only on effective tillers per square meter, number of grains per panicle. Effective tillers per square meter and number of grains per panicle both were the highest at 100 kg ha^{-1} seeding of *Sesbania* under *Sesbania* rice co-culture, which was significantly higher than the seed rate of 60 and 80 kg ha^{-1}, respectively and at par with seed rate of 80 and 60 kg ha^{-1}. Increasing seed rate of *Sesbania* under *Sesbania* rice co-culture slightly increased the thousand grains weight and decreased the sterility percentage. Killing dates of *Sesbania* under *Sesbania* rice co-culture only affect the number of grains per panicle among the several yield attributes measured. The highest number of grains per panicle was recorded while killing the *Sesbania* at 28 DAS which was equally effective when killed at 35 DAS and 42 DAS weeks and had greater response than killing at 21 DAS.

Seed rate of *Sesbania* had significant influence on the grain yield, but it had influenced the straw yields and harvest index, and killing dates of *Sesbania* had not influenced the grain yield, straw yield and harvest index (Table 3). The highest grain yield was recorded on the plots having 100 kg ha^{-1} seed rates of *Sesbania* was significantly higher than the grain yield obtained in the 60 kg ha^{-1} and statistically at par with the 80 kg ha^{-1} seeding of *Sesbania* under *Sesbania* rice co-culture. Straw yield was higher at 80 kg ha^{-1} seed rate of *Sesbania* and harvest index was higher at 100 kg ha^{-1} seed rate of *Sesbania*. Grain yield and harvest index was comparatively higher when killed *Sesbania at* 28 DAS, but straw yield was higher at killing the *Sesbania* at 21 DAS.

Table 3: Yield and yield component influenced by different seed rate and knocking down days of *Sesbania* at AFU Agronomy Farm, Rampur, Chitwan, Nepal, 2014

Treatments	Effective tillers per m^2	Grains per panicle	Thousand grains weight (g)	Sterility (%)	Grain yield (t ha^{-1})	Straw yield (t zha^{-1})	Harvest index (%)
Seed rate of *Sesbania*							
60 kg ha^{-1}	183.50^{b}	118.76^{ab}	18.42	17.24	3392.52^{b}	4902.97	37.00
80 kg ha^{-1}	206.25^{a}	113.33^{b}	18.48	17.12	3664.59^{ab}	5152.77	38.00
100 kg ha^{-1}	203.83^{a}	123.40^{a}	18.58	15.37	3956.63^{a}	4925.41	41.00
SEm (±)	4.38	2.07	0.05	0.87	135.8	104.77	0.40
LSD (0.05)	17.21	8.12	ns	ns	533.4	ns	Ns
Killing date (weeks after seeding)							
3rd week	194.00	113.42^{b}	18.57	16.16	3452.53	5247.08	36.00
4th week	205.00	122.70^{a}	18.45	15.58	3944.20	5000.72	40.00
5th week	198.56	121.69^{a}	18.40	17.80	3740.51	4814.23	40.00
6th week	193.89	116.19^{ab}	18.57	16.77	3547.75	4912.83	38.00
SEm (±)	7.09	2.13	0.09	0.98	172	228.33	0.40
LSD (0.05)	ns	7.37	ns	ns	ns	ns	Ns
CV, %	7.58	9.93	3.6	23.41	12.15	10.98	10.05
Grand mean	197.86	118.50	18.49	16.58	3671.25	4993.71	39.00
Weed free	286.00	110.37	18.14	9.65	4823.27	6764.17	37.00
Weedy check	40.67	62.03	16.93	20.69	440.96	999.47	76.00

Note: ns, non significant. Treatment means followed by common letter(s) within column are not significantly different among each other based on DMRT at 0.05 level of significance.

Optimum seed rates and killing dates of *Sesbania* under *sesbania*-rice co culture

The polynomial regression between the seed rates and killing dates of *Sesbania* with grain yield under *Sesbania* rice co-culture was presented on Figure 2 and Figure 3 respectively. The optimum seed rates and killing dates of *Sesbania* under *Sesbania* rice co-culture were obtained by differentiation of the respective equation and found as 31.67 days (nearly 32 days) and 102.28 kg ha^{-1} (nearly 102 kg ha^{-1}), respectively.

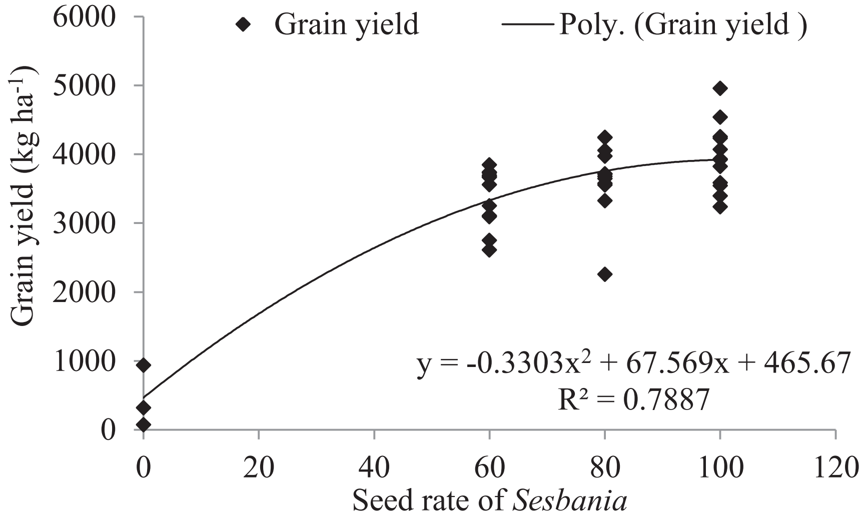

Figure 2: Relationship between seed rate of *Sesbania* and grain yield of rice under *Sesbania* rice co-culture at AFU Agronomy Farm, Rampur, Chitwan, Nepal, 2014

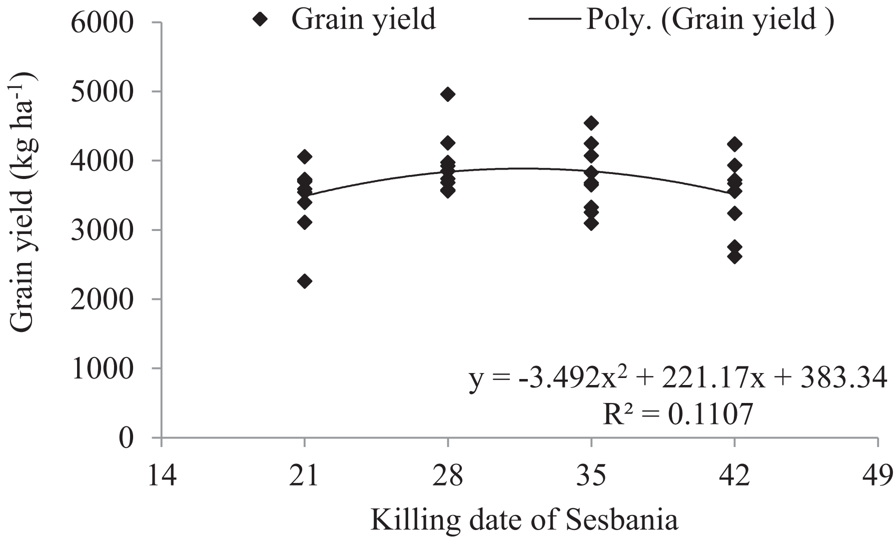

Figure 3: Relationship between killing dates of *Sesbania* and grain yield of rice under *Sesbania* rice co-culture at AFU Agronomy Farm, Rampur, Chitwan, Nepal,

DISCUSSION

Tillage and land preparation method greatly affect the weed biomass and frequency by reducing weeds seeds germination. Tillage practices determines the vertical distribution of weed seeds in soil profile and in turn affects crop establishment and weed emergence (Chauhan, Gill, & Preston, 2006). Two methods of seed bed preparation viz. normal seedbed and stale seedbed were used as main plot factor in the experiment. Stale bed was prepared by irrigating the field 13 days prior to sowing to allow weed seeds to germinate and finally weeds were killed by manual tillage, whereas in normal bed seeding was done after tilling the land without preparing stale seed bed. Enhancing weeds to germinate and their subsequent killing before rice sowing reduced the weed seed bank in the top layer of soil. In the present study, two methods of seed bed preparation did not significantly influence the grain yield (Table 2). The result observed was in contrast to the findings of Castin and Moody (1981), Rao et al. (2007) and Singh, Singh, Chauhan, Orr, Mortimer, Johnson, and Hardy (2008), where stale seed bed significantly lowered the density and dry weight of weeds and higher grain yield than in normal bed. The different result was obtained because first land preparation in both stale and normal bed was done at the same time and there was rainfall few days after application of irrigation to stale seed bed which germinated some of weed seeds in the normal seed bed as well. Also the soil in stale seed bed became compacted due to application of irrigation water which required slight intensive tillage compared to normal bed. As a result more weed seeds in lower depth were exposed and germinated in the stale seed bed which showed slightly more weed density and dry weight in initial observation which gradually declined compared to normal seed bed due to exhaustion of weed seed bank in later observations.

Among different herbicide treatments sequential application of herbicides showed better performance with respect to sole application which was similar to the findings of Fatemi (1990) and Singh et al. (2006). Application of pre emergence herbicide controlled the initial flush of weeds which was not done in sole post-emergence application of Bispyribac Na. Also sequential application of Pendimethalin with Bispyribac Na recorded lower weed density and dry weight compared to pre-emergence application of Pendimethalin followed by post emergence application of 2,4-D. This was because 2,4-D is effective against the broadleaves and sedges but Bispyribac Na provides broad spectrum control of broad leaves, grasses and sedges as well. Sole application of Bispyribac Na showed considerable higher weed density and dry weight contrast to the findings of Mahajan, Chauhan, & Johnson (2009), which was due to immediate rain after Bispyribac Na application. Then after delay of 4 days in re-spraying Bispyribac Na might have reduced its efficacy because by then weeds have matured and were not killed effectively.

The *Sesbania* co-culture with rice and knocking down *Sesbania* with selective herbicide produced comparable yield with famers' practice. *Sesbania* co-culture technology can reduce the weed population by nearly half without any adverse effect on rice yield (Kamboj *et al*., 2012). It involves seeding rice and *Sesbania* crops together and then knock down of *Sesbania* with 2, 4-D ethyl ester about 25-30 DAS. *Sesbania* grows rapidly and suppresses weed. This practice is found more effective in suppressing broad leaf weeds than grasses and, therefore, if combined with pre-emergence application of Pendimethalin, its performance in suppressing weeds increases (Singh, Ladha, Gupta, Bhushan, Rao, Sivaprasad, & Singh, 2007). This may largely be due to the rapid growth of *Sesbania* and, to some extent, mulch effects of its biomass. In addition to weed suppression, other benefits of *Sesbania* co-culture are atmospheric nitrogen fixation and facilitation of crop emergence in areas where soil crust formation is a problem (Gopal et al., 2010; Singh, Chhokar, Gopal, Ladha, Gupta, Kumar, & Singh, 2009). Despite these benefits, *Sesbania* co-culture may pose risks of competition with rice if 2, 4-D application is ineffective or 2, 4-D application is delayed and could also increase the cost of production. Moreover, *Sesbania* co-culture may limit the use of herbicides as some of these herbicides may knock down the *Sesbania* also.

Sesbania intercropping for 25-30 days in a Dry-DSR followed by killing of *Sesbania* using 2,4-D or mechanical weeding resulted small differences because of intercropping and short growth duration (Singh *et al*., 2007). This practice was also highly beneficial resource conservation technology for soil and water conservation, weed control and nutrient supplementation.

The *Sesbania* co-culture had produced significantly higher grain yield than sole Bispyribac Na application. Weed free, pre-emergence application of Pendimethalin + post emergence application of either Bispyribac Na or 2,4-D application and *Sesbania* with 100 kg seeds and killing at 28 weeks after seedling had showed statistically similar result (Table 1). Two hand weeding at 28 and 40 DAS as farmers' practice had only 4.79% yield advantage over *Sesbania* with 100 kg seeds and killing at 4th weeks after seedling under *Sesbania* rice co-culture. During the monsoon rice, the effectiveness of stale seed bed was not much greater (0.37%) than the normal seed bed. The optimum seed rates and killing dates of *Sesbania* under *Sesbania* rice co-culture were obtained as 31.67 days (nearly 32 days) and 102.28 kg ha^{-1} (nearly 102 kg ha^{-1}) respectively. The growing of *Sesbania* along with rice under dry-DSR had equally effective as farmers' practice of 2 hand weeding and best chemical weed management practices proving the best methods with respect to economics and environmental protection.

CONCLUSIONS

Sesbania co-culture had produced significantly higher grain yield than sole Bispyribac Na application. Two hand weeding at 28 and 40 DAS as farmers' practice had only 4.79% yield advantage over *sesbania* with 100 kg seeds and knock down at 28 days after seeding under *sesbania* rice co-culture. The optimum seed rates and knock down dates of *sesbania* under *sesbania* rice co-culture were calculated as 31.67 DAS and 102.28 kg ha^{-1}.

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