ESTIMATION OF ECONOMIC THRESHOLDS OF JUNGLE RICE (*ECHINOCHLOA COLONA* L.) AND FALSE AMARANTH (*DIGERA ARVENSIS* FORSSK.) IN DIRECT SEEDED RICE

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ABSTRACT

There is little understanding about economic thresholds of weeds in direct-seeded rice. To get estimates of economic thresholds of two weeds in direct seeded rice, two-year field trials were conducted at research area of College of Agriculture, University of Sargodha, Punjab-Pakistan. Treatments included 0, 22, 44, 66 and 88 plants m^{-2} densities of each of *Echinochloa colona* and *Digera arvensis* laid out in randomized complete block design. Augmented densities of *E. colona* (0, 22, 44, 66 and 88 weed plants m^{-2}) enhanced its plant dry biomass up to 348 and 353%; and relative competitive index maximally to 80 and 77% in years 2015 and 2016, respectively. While the corresponding increases in plant dry weight and relative competitive index of *D. arvensis* were 367 and 360% and 79 and 82%. The enhancement in N (up to 258 & 257 %), P (up to 220 & 232%) and K (up to 293 & 301%) uptake in years 2015 and 2016, respectively were made by *E. Colona* whereas the corresponding increases in N, P and K assimilation by *D. arvensis* were 265 & 257%, 238 & 233% and 305 & 298%, respectively. The declines in growth and yield of rice were observed in response to enhanced number of both the weeds. Rice grain yield losses ranged between 10 to 75% and 28 to 80% by *E. Colona* and *D. arvensis*. The economic thresholds of false amaranth and jungle rice were estimated to be 1.6-1.4 plants m^{-2} and 2.2-2.6 plants m^{-2}, respectively.

Keywords: Economic threshold, density, false amaranth, jungle rice, yield losses

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INTRODUCTION

One of staple food crop that feeds billions of world population is rice (*Oryza sativa* L.) (Ashraf *et al.,* 2006), and over half of the human habitation depends on it for its daily livelihood (Chauhan and Johnson, 2011). The rice is cultivated in 114 countries of the world, feeding above than half of the world, from which 90% production is solely contributed by Asia (FAO, 2011). Fine grain rice which is branded as basmati rice fetches an attractive international price and pays a huge amount in foreign exchange, sharing 3.2% in agriculture value addition and contributes 0.7% in GDP (Government of Pakistan, 2015). In Pakistan, rice is positioned as second after wheat among food grains, important cash crop, and export commodity which earns US$ 1,594 million foreign exchange annually (Government of Pakistan, 2020). The cultivated land occupied by the paddy is about 3.0 M ha with an yearly production of 7.4 M tonnes (Government of Pakistan, 2020).

The traditional method of rice sowing is seedling's transplantation in the puddled soils and the land is kept flooded throughout the growing season which promises good crop initiation, an efficient weed culmination and reduces water infiltration losses (Rao *et al.,* 2007). From the opposed point of view, the traditional rice nursery transplantation is very laborious, burdensome, expensive, time consuming and results in delayed transplantation of rice seedlings with above-optimal age. Moreover, shortage of skilled labor and carelessness during manual transplanting result in low plant density in field delivering a low yield (Mann and Ashraf, 2001). It is predicted that in forthcoming years, the rice growers will face scarcity of irrigational water (Tuong and Bouman, 2003). Therefore; this scarcity is an overwhelming risk to continuity of conventional transplanted rice (Saqib *et al.,* 2015).

Under the current scenario, the direct-seeded rice (DSR) seems a feasible substitute in redeeming farmers' economy (Farooq *et al.,* 2011). It has ability to ensure higher water use efficiency along with an elimination of possible soil moisture related issues that affect plant growth in cropping system having wheat followed by rice. In DSR technique, the seed of rice is directly sown in a well-prepared or in zero-tilled soil and irrigation is managed as per requirement to sustain the soil moisture at field capacity. It has been pointed out that in DSR, there is a saving of irrigational water up to 11-18% (Tabbal *et al.,* 2002) as well as a reduction in labor requirements up to 11-66% as compared to puddled transplanted rice (PTR) according to prevailing season, area as well as the nature of method adopted to sow DSR. Other rewards of DSR are rapid and easy sowing, improvement in soil health, an increased water stress tolerance, reduced methane gas emission along with higher profit margins in areas having ensured supply of irrigational water (Kumar and Ladha, 2011). Moreover, the DSR is also related to an early maturity than PTR facilitating oncoming wheat sowing at appropriate time (Singh *et al.,* 2006). The DSR can be harvested at least 7-10 days earlier than conventional PTR (Singh *et al.,* 2008), due to which the timely sowing of wheat, mustard, lentil and potato becomes feasible.

During a transformation from traditional PTR to DSR, the weed control becomes a major problem (Rao *et al.,* 2007). In PTR, the standing water suppresses most of the germinating weeds as well as newly established transplanted seedlings of rice ensure 'head start' on emerging weeds (Rao *et al.,* 2007). On the other hand, in DSR the weeds germinate along with the emerging rice plants creating a serious competition with rice (Khaliq and Matloob, 2011). Hence, the weeds occurrence is a substantial barrier in making DSR a successful crop (Chauhan, 2012) and the failure in weed control results in the yield loss fluctuating from 60-100% under severe weed infestation (Rao *et al.,* 2007: Nadeem et al., 2020a: Nadeem et al., 2020b). The yield of DSR can be increased manifolds by adopting an integrated weed management (IWM) plan which is an combination of different weed control techniques to lessen the weed population to a tolerable level while sustaining the uniqueness of a particular habitat, water as well as diverse natural resources (Blackshaw *et al.,* 2005).

To launch any weed management strategy, a necessary precondition is to figure out economic threshold level (ETL) of a particular weed. Economic threshold level of a weed is that population density of the particular weed upon which the expense of weed control is equivalent to increased crop price gained due to weed control. A weed control above an ETL will result in greater net returns of a crop while, a weed control below the ETL will result in lower net crop returns. A very limited research work has still been undertaken to determine an ETL of different weeds prevalent in DSR. However, some efforts have been done in this regard under puddled rice conditions. In an experiment, it was found that only 60 *Echinochloa* spp. plants / m^2 caused 60% reduction in yield of DSR, whereas 96 *Echinochloa* spp. plants / m^2 caused an identical yield decline in TPR of similar density which means that *Echinochloa* weeds are much more competitive in DSR as compared to TPR (Gwon *et al.*, 2006). In Korea, Kwon *et al.* (2007) found that *E. crus-galli* density of 96 plants m^{-2} and *Cyperus difformis* density of 576 m^{-2} reduced the yield of rice by 51-60 and 18-19%, respectively under TPR conditions. The economic thresholds of these weeds were 0.8-1.1 and 27.8-28.8 plants m^{-2}, respectively. However, 2.77 plants m^{-2} is the economic threshold of *E. crus-gall* and *C. difformis* mixture in rice (Tian *et al.*, 2020). The economic threshold of mixed weed flora consisting of *C. difformis* , *Cyperus. iria* L., *Fimbristylis miliacea* L., *Scirpus maritimus* L., *Cynodon dactylon* L. Pers., *E. crus-galli*, *Leptochloa chinensis* L. Nees., *Marsilea minuta* L., Monochoria *vaginalis* Burm. f., *Sphenoclea zeylanica* Gaertn, *Leersia hexandra* Sw. and *Ludwigia octovalvis* Jacq. was 4.72–9.17 plants m^{-2} with grain yield losses of 29-42% (Al-Mamun, 2014).

At weed densities below their economic threshold, it would not be feasible for farmers to exhaust their economic assets for controlling those weeds. The present study was therefore executed to decide the impacts of *E. colona* and *D. arvensis* densities on growth and yield of DSR, and also to evaluate their ETLs.

MATERIALS AND METHODS

Two-year field experiments were executed at research area (Latitude 32.13°N, longitude 72.68°E and altitude 189 m) of Agronomy Department, College of Agriculture, University of Sargodha, Punjab-Pakistan during summers of two consecutive years 2015 and 2016. The experiment was carried out on fine silty soil with pH 7.8, 0.73% organic matter, 0.04% N, 6.3 ppm available P and 158 ppm available K. The monthly averages of temperatures varied from 24.6^{o}C to 31.2^{o}C in year 2015 and 25.9^{o}C to 34.7^{o}C in year 2016, while the total rainfalls ranged between 865.5 mm to 1244.5 mm in years 2015 and 2016, respectively. (Table 1).

Table 1: Two-year (2015-2016) meteorological data of experimental site during crop growing period

Month	Temperature (^{0}C)			Relative Humidity (%)	Total Rainfall (mm)
	Max.	Min.	Mean		
2015					
June	36.4	25.7	31.2	48.3	277.11
July	34.3	27.4	30.7	63.5	221.23
August	34.2	26.7	30.4	70.2	211.59
September	33.3	24.6	28.8	63.9	89.92
October	30.2	19.5	24.6	63.0	66.05
Total					**865.59**
2016					
June	39.4	29.6	34.7	44.5	267.97
July	35.2	27.9	31.5	64.1	539.49
August	34.4	27.1	30.6	67	423.16

September	34.8	25.8	30.3	61.8	13.97
October	32.6	20.3	25.9	57.2	0
Total					**1244.59**

The experiment was comprised of densities (0, 22, 44, 66 and 88 plants m^{-2}) each of *Echinochloa colona* and *Digera arvensis* and was laid out in randomized complete block design The field heavily infested with weeds during the previous year was selected for experiment. Super-basmati variety of fine rice was as sown on a well pulverized flat seed bed in 25 cm apart rows with single row hand drill using seed rate 35 kg ha^{-1} on 4^{th} and the June in 2015 and 2016, respectively. Phosphorus, potash and nitrogen were applied at 75, 135, and 60 kg ha^{-1} in the form of di-ammonium phosphate (DAP), sulphate of potash (SOP) and urea, respectively. Entire P_2O_5 and K_2O along with $1/3^{rd}$ nitrogen were applied at the time of final seed bed preparation. The rest one third of nitrogen was broadcasted at tillering stage [30 days after sowing (DAS)] while one third at the time of panicle initiation (65 DAS) growth stage of rice. As crop protection measure, a granule insecticide Stark 4G (cartap hydrochloride) was applied at 22 kg ha^{-1} 25 DAS to control rice borers, and insecticide Karate 5EC (lambda-cyhalothrin) at 0.62 L ha^{-1} was used twice as a foliar application in the mid-August to control rice leaf folder. Moreover; rice crop was also sprayed with a fungicide Thiophenate-methyl (Topsin-M 70WP) at 1.0 kg ha^{-1}at the end of September as a preventive measure against rice paddy blast. The crop was manually harvested near maturity on November 12, 2015 and November 15, 2016. A total of twelve irrigations were applied to keep the field at a proper moisture level to prevent the crop from moisture stress.

The various attributes of jungle rice and false amaranth such as their respective dry biomasses, relative competitive indices (RCI), and NPK uptakes were assessed. Dry biomasses of both weeds were recorded by cutting these near the ground level from an entire plot at rice harvest after 48 hours of drying in constrained-air oven. Yield and yield related traits were observed near crop maturity and at crop harvest in each plot. Rice grain yield was divided by biological yield to get harvest index that was expressed in percentage.

The analysis of two-years data was performed separately as there was heteroscedasticity in environmental conditions in years 2015 and 2016. The data were evaluated statistically by employing Fisher's analysis of variance method and the comparison between various treatment means was carried out by employing Tukey's honestly significant difference (HSD) test at significance level of 5% (Steel *et al.,*1997) utilizing Statistix 8.1 (Analytical Computer Software 2005). The trend comparison was performed to detect linear, quadratic as well as cubic trends in data in response to increasing jungle rice and false amaranth densities. A modified rectangular hyperbolic regression model developed by Cousens (1985) and successfully used by Moon *et al.* (2012) was applied on rice grain yield along with jungle rice and false amaranth densities to explore the relationship among rice grain yield (Y) as well as jungle rice and false amaranth densities. The equation presenting the model is as under:

$$Y = Yo / (1 + \beta x) \qquad \text{Equation 1}$$

Where Y represents estimated grain yield (t ha^{-1}) of rice at a particular weed density level, Y_o represents the grain yield of rice in weed-free plot (t ha^{-1}), and β shows the weed competitiveness (a 1/β density of weed reduces the grain yield of rice by 50%).

While x = jungle rice / false amaranth weed density. An estimation of ETLs of both weeds were computed by comparing the price needed for managing these weeds with rice yield worth attained as a result of herbicide application. These calculations were made through equation 2 devised by Cousens (1987):

$$ET = (Ch + Ca) / (Yo\ PLH)$$

Equation 2

Where Ch is herbicide cost (PKR/ha), Ca is herbicide spray cost (PKR/ ha), Y_o indicates the paddy yield (t/ha) in weed-free treatments, P is value of crop per unit of its produce (PKR/ha), L is proportionate loss per unit of weed density and H represents the herbicide efficacy (a proportional decrease in weed density or biomass of weed due to utilization of herbicide).

RESULTS

Growth characteristics of jungle rice and false amaranth

Analysis of the data revealed that the dry biomasses of jungle rice and false amaranth were significantly altered by their changing densities. A gradual increase in jungle rice as well as false amaranth's dry biomasses was noted with rise in their densities (22 to 88 plants m^{-2}) during both the years of study (Table 2 & 3). The highest density (88 plants m^{-2}) of jungle rice and false amaranth dispensed significantly the highest dry biomasses (451 and 672 g m^{-2}, respectively) which were followed by those with their respective densities maintained at 66, 44 and 22 plants m^{-2}. Nevertheless, a population of 22 plants / m^2 gave minimum jungle rice (118.9 and 127.7 kg ha^{-1}) and false amaranth (179.8 and 186.8 kg ha^{-1}) dry weights in first and second experimental year, respectively. Trend comparisons showed significant linear and cubic responses to elevating densities of jungle rice and false amaranth (22-88 plants m^{-2}), respectively.

The relative competitive index (RCI) was enlarged due to a gradual incline in respective densities of jungle rice as well as false amaranth. A higher jungle rice RCI (80% in year 2015 and 77.3% in year 2016) and false amaranth (80.1% in year 2015 and 79.7% in year 2016) was observed at their 88 weeds plants m^{-2} (Table 2 & 3). Contrastingly, the lowest RCI of both weeds was noted at their lower most density (22 plants m^{-2}).

Table 2: Effect of *E. colona* density in rice crop on weed dry biomass, RCI, and major nutrient absorption

***E. colona* density (m^{-2})**	**Dry biomass ($g\ m^{-2}$)**		**Relative competitive index (RCI) (%)**		**N uptake ($kg\ ha^{-1}$)**		**P uptake ($kg\ ha^{-1}$)**		**K uptake ($kg\ ha^{-1}$)**	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
0	0 e	0 e	-	-	0 e	0 e	0 d	0 e	0 e	0 e
22	118.9 d	127.7 d	8.0 d	10.30 d	5.63 d	6.19 d	0.75 c	0.79 d	5.73 d	6.16 d
44	222.9 c	232.3 c	21.59 c	22.75 c	10.08 c	10.44 c	1.20 b	1.24 c	10.08 c	10.49 c
66	329.3 b	340.3 b	53.34 b	48.07 b	13.58 b	14.07 b	1.53 a	1.59 b	14.03 b	14.53 b
88	414.0 a	451.0 a	77.26 a	75.03 a	14.53 a	15.96 a	1.65 a	1.84 a	16.82 a	18.57 a
HSD	18.32	20.81	3.94	5.05	0.803	0.823	0.166	0.134	0.893	0.897
Trend comparison										
Linear	**	**	**	**	**	**	**	**	**	**
Quadratic	**	NS	**	**	**	**	**	**	**	**
Cubic	NS	NS	**	NS	*	NS	NS	*	NS	*

Mean values in a column with dissimilar lettering vary significantly (P < 0.05) from one another based on Tukey's honestly significant difference (HSD) test, ** evinces significant at P < 0.01

Nutrient uptake by jungle rice and false amaranth

Phosphorus (P), potash (K) and nitrogen (N) uptakes by jungle rice and false amaranth were enhanced with the increment in their respective density levels (22-88 weeds plants m^{-2}) (Table 2 & 3). For jungle rice, P, K and N uptakes were increased up to120%, 139%and 171%, respectively. While P, K and N uptakes by false amaranth were improved maximally to 138%, 205% and 165%, respectively. The trend comparison regarding jungle rice N-uptake at its elevating densities (22 to 88 weed plants m^{-2}) remained cubic in 2015 while quadratic in 2016. The trend of P and K uptake by jungle rice at its elevating densities (22-88 plants m^{-2}) remained quadratic in 2015 while cubic in 2016.The response of P, K and N uptake increase by false amaranth to its elevating densities (22 to 88 plants m^{-2}) was cubic in both the years of study except K uptake that followed a linear pattern in year 2016.

Table 3: Effect of *D. arvensis* density in rice crop on weed dry biomass, RCI, and major nutrient uptake

D. arvensis density (m^{-2})	Dry biomass ($g\ m^{-2}$)		Relative competitive index (RCI) (%)		N uptake ($kg\ ha^{-1}$)		P uptake ($kg\ ha^{-1}$)		K uptake ($kg\ ha^{-1}$)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
0	0 e	0 e	-	-	0 e	0 e	0 e	0 e	0 e	0 e
22	179 d	186 d	27.7 d	27.2 d	8.72 d	9.1 d	1.12 d	1.18 d	8.7 d	9.1 d
44	263 c	273 c	53.5 c	57.3 c	11.8 c	12.3 c	1.43 c	1.52 c	11.9 c	12.4 c
66	411b	418 b	66.0 b	67.3 b	16.9 b	17.3 b	1.91 b	1.97 b	17.6 b	17.9 b
88	660 a	672 a	79.1 a	80.3 a	23.1 a	23.6 a	2.67 a	2.75 a	26.6 a	27.3 a
HSD	38.51	40.50	3.59	3.58	1.468	1.56	0.209	0.222	1.863	1.605
Trend comparison										
Linear	**	**	**	**	**	**	**	**	**	**
Quadratic	**	**	**	**	*	*	*	**	*	NS
Cubic	**	**	*	**	**	**	**	**	**	NS

Mean values in a column with dissimilar lettering vary significantly ($P < 0.05$) from one another based on Tukey's honestly significant difference (HSD) test, ** evinces significant at $P < 0.01$

Yield and yield traits of rice

Productive tillers count

Significantly the highest productive tillers m^{-2} (426 & 478 m^{-2} and 462 & 436 m^{-2}) of rice were counted from control plots in jungle rice and false amaranth experiments in years 2015 and 2016, respectively (Table 4 & 5). A significant linear drop in this trait occurred at and beyond jungle rice and false amaranth density of 22 plants / m^2 consistently over both the years. Consequently, 88 plants / m^2 of both weeds brought forth the lowest rice tillers count(188 m^{-2} in year 2015 & 216 in years 2016; and 207 in year 2015 & 203 in the year 2016), respectively.

Grains per panicle

The paddy yield of rice crop is positively associated with its grain count / panicle. The two-year data of this parameter is shown in Tables 3 and 4. Weed free plots attained the maximum grain count (110 & 112 $panicle^{-1}$ and 116 & 106 $panicle^{-1}$) of rice in jungle rice and false amaranth experiments during the two subsequent years, respectively. The significant drop in grain count / panicle of rice was noted at and beyond jungle rice density of 44 plants / m^2 and false amaranth density of 22 plants / m^2. Nevertheless, the minimal values of grain count (80.8 & 88.3 $panicle^{-1}$ and 69.2 & 79.3 $panicle^{-1}$) were noted with the highest (88 plants m^{-2}) jungle rice and false amaranth density during years 2015 and 2016, respectively. A linear response of this parameter to elevated jungle rice density (from 22 to 88 plants / m^2) was detected consistently over both the years. However, in false amaranth experiment, trend comparison was found linear during year 2016 while cubic during year 2015.

1000-grain weight

Significant difference was observed regarding rice 1000-grain weight as influenced by various jungle rice as well as false amaranth elevating densities (Tables 4 and 5), respectively. This trait was decreased significantly as the densities of jungle rice and false amaranth were boosted from their densities of 22 to 88 plants m^{-2}. The highest 1000-grain weights of rice in jungle rice (22.51 & 23 g) and false amaranth (22.67 & 21.75 g) experiments were counted from weed free plots during years 2015 and 2016, respectively. Nevertheless, during both years of study, by increasing density both weeds to 22 plants / m^2, significant decline in grain weight of rice was noticed. Consequently, 88 plants / m^2 of jungle rice and false amaranth produced minimum1000-grain weight (17.21 & 17.32 g and 18.52 &18.22 g) of rice during years 2015 and 2016, respectively. The decline in grain weight of rice in response to elevated densities of jungle rice (22 to 88 plants m^{-2}) followed linear trend in both years while the trend comparison to false amaranth rising densities was linear in year 2015 but cubic in year 2015.

Table 4: Effect of *E. colona* density in rice on paddy yield and yield related traits

***E. colona* density (m^{-2})**	**Number of Productive tillers (m^{-2})**		**Rice grains / panicle**		**1000 grain weight (g)**		**Paddy yield (t ha^{-1})**		**Harvest index (%)**	
	2015	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**	**2015**	**2016**
0	426 a	478 a	110 a	112 a	22.5 a	23.0 a	3.64 a	3.80 a	23.0 a	23.5 a
22	359 b	379 b	105 a	107 a	21.2 b	21.6 b	3.32 b	3.41 b	22.2 b	22.5 b
44	323 b	331 c	97.7 b	101 b	19.9 c	20.3 c	2.85 c	2.93 c	20.3 c	21.3 c
66	251 c	275 d	85.7 c	96.9 b	18.1 d	18.4 d	1.70 d	1.97 d	18.4 d	19.2 d
88	188 d	216 e	80.8 c	88.3 c	17.2 e	17.3 e	0.82 e	0.95 e	17.1 e	17.2 e
HSD Value	**42.71**	**27.80**	**6.44**	**5.86**	**0.61**	**0.75**	**0.2194**	**0.2511**	**0.69**	**0.73**
Trend comparison										
Linear	**	**	**	**	**	**	**	**	**	**
Quadratic	NS	**	NS	NS	NS	NS	**	**	NS	NS
Cubic	NS	**	NS	NS	NS	NS	**	NS	NS	NS

Mean values in a column with dissimilar lettering vary significantly (P < 0.05) from one another based on Tukey's honestly significant difference (HSD) test, ** evinces significant at P < 0.01, Values in parenthesis show percent decrease in grain yield over zero (check)

Table 5: Effect of *D. arvensis* density in rice on crop grain yield and yield components during two growing seasons

D.arvensis density (m^{-2})	Number of Productive tillers (m^{-2})		Rice grains / panicle		1000 grain weight (g)		Paddy yield (t ha^{-1})		Harvest index (%)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
0	436 a	462 a	106 a	116 a	21.7 a	22.6 a	3.62 a	3.81 a	22.7 a	23.6 a
22	358 b	376 b	89.5 b	103 b	20.5 b	20.9 b	2.63 b	2.75 b	21.5 b	22.5 b
44	309 c	329 c	83.5 b	96.8 bc	19.8 bc	20.0 c	1.54 c	1.77 c	19.6 c	20.0 c
66	281 c	279 d	75.7 c	90.9 c	19.1 cd	19.3 d	1.18 d	1.29 d	18.0 d	18.7 d
88	203 d	207 e	69.2 d	79.3 d	18.2 d	18.5 e	0.71 e	0.79 e	16.6 e	17.1 e
LSD Value	**37.28**	**36.15**	**6.13**	**10.81**	**1.14**	**0.59**	**0.1782**	**0.2066**	**0.85**	**0.64**
Trend comparison										
Linear	**	**	**	**	**	**	**	**	**	**
Quadratic	NS	NS	**	NS	NS	**	**	**	NS	NS
Cubic	NS	NS	**	NS	NS	*	NS	NS	NS	NS

Mean values in a column with dissimilar lettering vary significantly ($P < 0.05$) from one another based on Tukey's honestly significant difference (HSD) test, ** evinces significant at $P < 0.01$, Values in parenthesis show percent decrease in grain yield over zero (check)

Paddy yield

It can be seen that paddy yield was decreased progressively and significantly as the jungle rice and false amaranth densities were augmented from 22 to 88 plants / m^2. Significantly the highest paddy yields (3.64 & 3.80 t ha^{-1} and 3.81 & 3.62 t ha^{-1}) were recorded from weed-free plots of jungle rice and false amaranth experiments during the two consecutive years (Table 4 & 5), respectively. The paddy yield suffered from significant decline with the progressive incline in densities of the respective weeds from 22 to 88 plants m^{-2}. Thus, the lowest (0.82 & 0.95 t ha^{-1} and 0.79 & 0.71 t ha^{-1}) paddy yields were obtained from plots infested with highest (88 plants m^{-2}) jungle rice and false amaranth densities in years 2015 and 2016, respectively. Paddy yield followed cubic and quadratic trend to increasing jungle rice densities (22 to 88 plants m^{-2}) during the year 2015 and 2016, respectively. However, this trend in case of false amaranth remained quadratic through both the years.

Harvest index (%)

An outlook of data regarding HI (Tables 4 & 5) for both of the weeds for the two sequential years disclosed that rising densities of jungle rice and false amaranth significantly influenced the HI of rice. The highest HI of jungle rice (23.06 & 23.54%) and false amaranth (23.68 & 22.77%) were obtained by their weed free controls in years 2015 and 2016, respectively. However, significant decline in this parameter began from density of 22 plants / m^2 of both the weeds in both the years. Resultantly, the peak population densities of jungle rice and false amaranth attained the lowest HI (17.12 &17.27%and 17.19 & 16.60%) during the two successive years, respectively. The trend comparisons of diverse jungle rice densities (22 to 88 weed plants m^{-2}) remained linear in the year 2015, while quadratic in the year 2016.

Estimation of economic threshold of weeds in DSR

By applying the rectangular hyperbola on rice grain yield, the jungle rice-free paddy yield was predicted to be 3.6 t ha^{-1} in year 2015, while 3.8 t ha^{-1} in year 2016 (Figures 1a & 1b), while it was estimated to be 3.8 and 3.6 t ha^{-1}, respectively (Figures 2a & 2b) in case of false amaranth-free plots for the same subsequent study years. The competitiveness of weed (β) whose reciprocal is (1/β), represents the density of jungle rice and false amaranth weeds which decreases the crop yield up to 50%, was found to be 0.015 and 0.020 during first- and second-year experiments, respectively. The model was found to be good fit revealing that the respective competition amongst rice and jungle rice as well rice and false amaranth were clarified very well by an application of hyperbolic model. By maintaining the weedicide cost at PKR 3212 & PKR 3360, application cost at PKR 600 and PKR 800, per unit value of crop at PKR 32500 and PKR 42500; an economic threshold (ET) regarding jungle rice was assessed as 2.2 weeds plants m^{-2} for year 2015 and 2.8 weeds plant m^{-2} for years 2016 (Table 6). While ETL values for false amaranth were approximated to be 1.6 and 1.4 weeds plants / m^2 for the years 2015 and 2016, respectively (Table 7).

Table 6: Parameters estimation and economic threshold level (ET) of jungle rice in rice

Weed	**Year**	**C_h**	**C_a**	**Y_o**	**P (PKR ton^{-1})**	**L**	**H**	**ETL (plants m^{-2}) (C_h + C_a) / (Y_o PLH)**
Jungle rice	**2015**	3212	600	3.6	32500	0.015	0.95	2.2
	2016	3360	800	3.8	42500	0.015	0.95	2.8

Where C_h is herbicide cost, C_a is an application cost, Y_o is weed free paddy yield, P is value of per unit of crop, L is proportional loss per unit weed density, and H is herbicide efficacy was supposed to be 0.95

Table 7: Parameters estimation and economic threshold level (ET) of false amaranth in rice

Weed	**Year**	**C_h**	**C_a**	**Y_o**	**P (PKR ton^{-1})**	**L**	**H**	**ETL (plants m^{-2}) (C_h + C_a) / (Y_o PLH)**
False amaranth	**2015**	3212	600	3.8	32500	0.02	0.95	1.6
	2016	3360	800	3.6	42500	0.02	0.95	1.4

Where C_h is herbicide cost, C_a is an application cost, Y_o is weed free paddy yield, P is value of per unit of crop, L is proportional loss per unit weed density, and H is herbicide efficacy was supposed to be 0.95

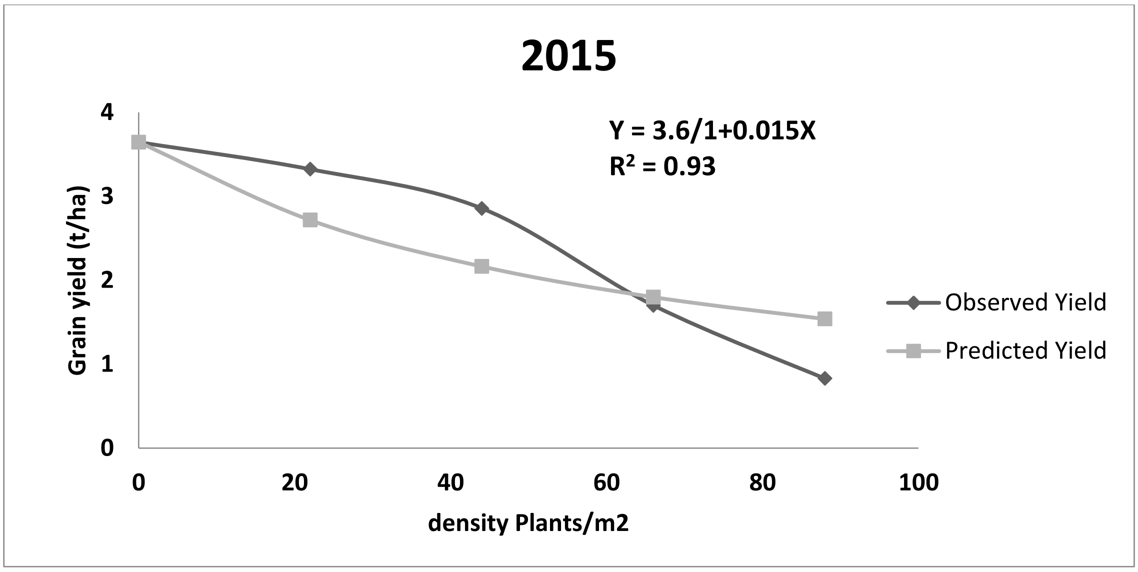

Figure 1(a): Polynomial regression model (according to Cousen's Model) on *E. colona* in rice

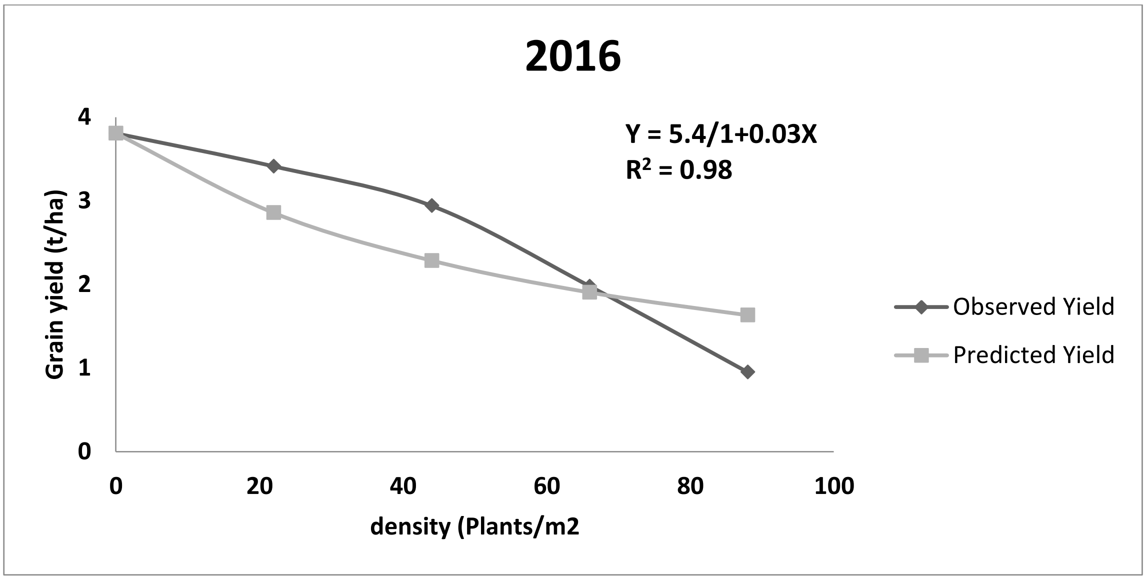

Figure 1(b): Polynomial regression model (according to Cousen's Model) on *E. colona* in rice

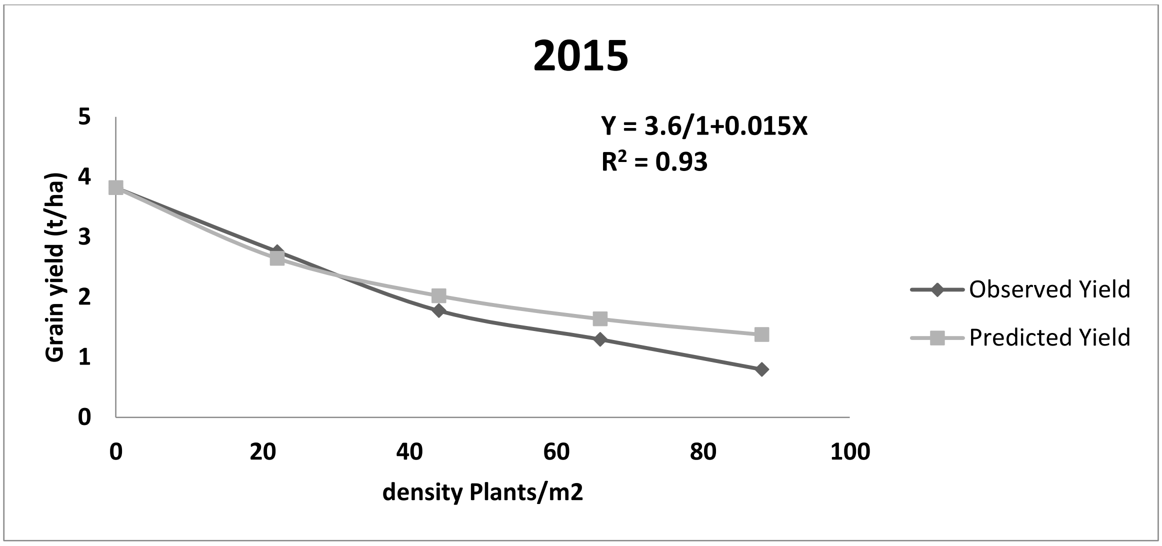

Figure 2(a): Polynomial regression model (according to Cousen's Model) on false amaranth in rice

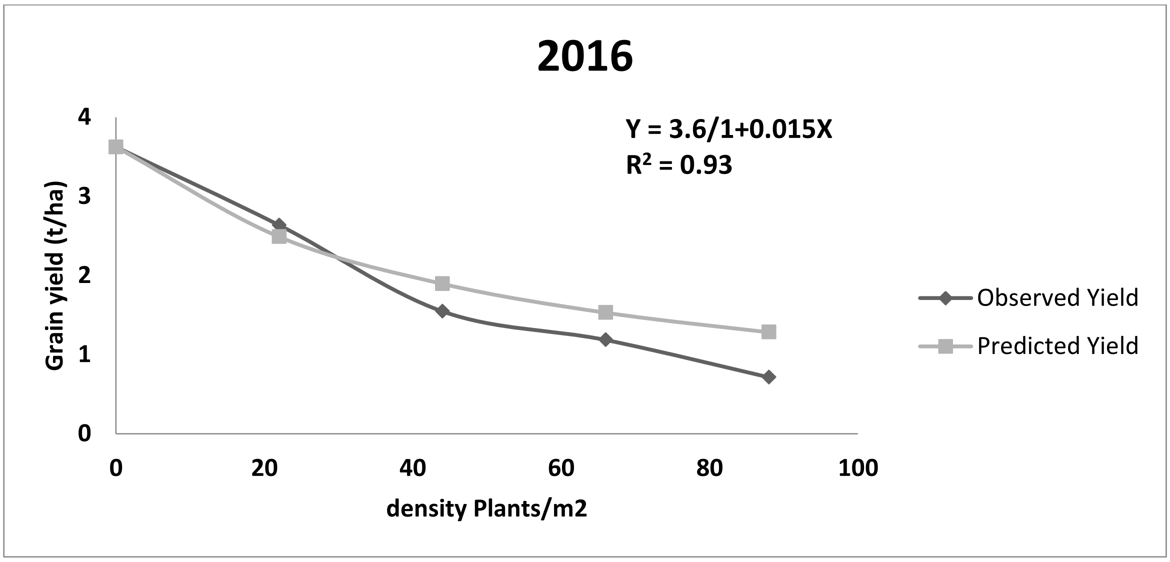

Figure 2(b): Polynomial regression model (according to Cousen's Model) on false amaranth in rice

DISCUSSION

The weed infestation and associated yield losses are much higher in DSR compared to those in TPR (Rao *et al.*, 2007). A very fewer or no studies have been conducted regarding ecological interference of weeds in DSR. Statistically a significant dry biomass / m^2 of both weeds was observed with their increasing densities from 22 to 88 weeds plants m^{-2}. This increase in the dry weight of jungle rice as well as false amaranth was resulted due to their greater number of plants / unit area that accumulated a higher biomass / unit area. Mishra *et al.* (2006) stated that increased number of weed plants resulted in their increased dry weight. Al-Mamun *et al.* (2013) demonstrated that as a result of an increase in the densities of saltmarsh bulrush (*Scirpus maritimus*), its dry matter production was also enhanced. The outcomes of current studies are in accordance with findings of Cortés *et al.* (2010) who concluded that as a result of expanding densities of velvetleaf (*Abutilon theophrasti* Medik.) in cotton crop, weed biomass was proportionally expanded. In the same way, Morales-Payan (2000) watched an enlargement in weed biomass of *Parthenium hysterophorus* with its expanding densities in tomato (*Lycopersicon esculentum* Mill.). Nonetheless, Hussain *et al.* (2011) demonstrated an expansion in dry biomass of common cocklebur (*Xanthium strumarium*) by increasing its density in maize fodder. Mishra *et al.* (2006) also stated that the increased density of weeds resulted in its increased dry weight. A density of *P. hysterophorus* up to 20 plants / m^2 enhanced it dry biomass as far as 433% (Safdar *et al.,* 2015).

The RCI of a weed is an index of its inhibitory impact of weeds on crop yield (Smith *et al.*, 2015). Increased RCI of jungle rice and false amaranth with their expanded densities was due to increased degree of decline in paddy yield of rice. This happened probably on account of greater weed competition stress suffered by rice plants that reduced the rice growth and ultimately its yield. Our end results corroborate the findings of Mehmood *et al.* (2018) who declared rice yield losses ranging from 21 to23% with increasing densities of alligator weed and reported ETLs of alligator weed as 1.5 and 1.3 weeds plant / m^2. Yu *et al.* (2007) recorded a loss in paddy yield (43-50%) with the increasing densities (23 to 180 plants m^{-2}) of *Alternanthera philoxeroides* with rice population density of 100 plants / m^2. Karim and Firdous (2010) also pointed out a reduction in the paddy yield by 2.6 to 54% due to the infestation of *Echinochloa indica* at its population density of 28 to 224 plants m^{-2}, respectively. Babu (2012) reported a decrease in yield from 48 to 86% with the increased densities of jungle rice from 50 to 400 plants m^{-2} whereas the highest rice grain yield was attained from weed-free treatment. Al-Mamun *et al.* (2013) also quoted the highest paddy yield in plots with weed-free treatments. Kankal (2015) noticed a higher grain yield of rice from weed free plots under direct-seeded conditions. Subbaiah (2008) mentioned statistically significant drop in paddy yield of DSR when the density of jungle rice was increased from its 2 to 6 weed plants m^{-2}.

The ascending densities of jungle rice and false amaranth significantly impacted the N, P as well as K uptake. An increasing tendency in uptake of these nutrients was noticed in response to increased jungle rice as well as false amaranth densities. The NPK uptake was augmented progressively with the increased densities (22 to 88 plants m^{-2}) of jungle rice and false amaranth. That was due to a higher dry matter production by these weeds per unit area. Mandal et al. (2011) reported N, P and K -uptakes of 41.5, 9.1 and 57.9 kg ha^{-1}, respectively by weeds in direct-seeded rice. Aamer and Cheema (2006) also reported the highest N-uptake (180 kg ha^{-1}) from 16 plants m^{-2} of barnyard grass in transplanted rice. Revathi (2009) also observed lower N-depletion by weeds at their lower densities. Singh *et al.* (1991) stated that 140 plants m^{-2} of wrinkle grass depleted 63 and 103.6 kg / ha of P and K, respectively in transplanted rice.

Tillering capability of rice is amongst most substantial agronomic factor related to its grain production. With the increased jungle rice and false amaranth densities, a competition for space among rice plants and with these weeds was also intensified that triggered a decline in productive tiller count of rice crop. That is why; fertile tillers of rice decreased linearly with an amplification of jungle rice and false amaranth densities. Sultana (2000) pointed out that due to increased weed competition a decline of 52% in fertile tillers count was observed in DSR. Islam *et al.* (2003) counted maximum productive tillers of rice in treatments with weed-free plots in DSR. Al-Mamun *et al.* (2013) counted maximum tillers of rice in weed-free plots that declined gradually with the increasing weed densities. Babu (2012) also pointed out reduction in yield attributes of rice due to reduction in fertile tillers of rice as a result of increasing jungle rice density.

The grains count / panicle of rice was reduced gradually when the jungle rice and false amaranth densities were elevated from their 22 to 88 plants / m^2. The reduction in grain count of rice at elevated densities of weeds was attributed to aggravation in weed competition stress at its panicle development stage. The highest grain count / panicle of rice in plots subjected to zero-weed competition was resulted due to an existence of weed free environment for crop that pushed higher proportion of growth resources towards crop. Karim and Firdous (2010) reported reduced grain count / panicle with increased densities of weeds. Babu (2012) also stated higher grain number / panicle in weed free control plots. Al-Mamun *et al.* (2013) also pointed out that the elevated densities of weeds influenced the grains / panicle significantly in paddy.

Yield estimation is usually accomplished by 1000-grain weight which is governed by genetic makeup of a crop but to some extent by prevailing growing conditions. In comparison to weed-free control, 1000-kernal weight of rice was declined significantly with a rise in the densities of jungle rice and false amaranth. This could be attributed to the existence of higher weed competition stress during grain filling period of rice crop that reduced its grain weight. Begum *et al.* (2009) reported that with increasing *Fimbristylis miliacea* density, 1000-grain weight of rice was substantially reduced. Karim and Ferdous (2010) revealed that increasing barnyard grass and goose grass density significantly reduced the 1000-kernal weight of rice. Al-Mamun *et al.* (2013) also revealed the highest 1000-kernal weight of rice in weed-free treatment. Nahar *et al.* (2010) and Khan and Tarique (2011) reported a higher rice 1000-grain weight in weed-free environment throughout the crop growing period.

The pooled effect of different yield related traits governs the final yield of a crop. A decrease in paddy yield of rice in response to an incline in the jungle rice and false amaranth densities was noted in response to decline in under lying yield related traits such as fertile tillers, grain / panicle and grain weight. The major yield determining component of rice which contributed more in final paddy yield was proved to be productive tillers count as shown by their regression analysis. The strong dependence of paddy yield on number of tillers / m^2 of rice was reflected by values of regression coefficients (R^2) in jungle rice (0.835 & 0.820) and false amaranth (0.680 & 0.734) experiments for the years 2015 and 2016, respectively (Data not shown). The gradual decline rice growth and yield by increasing weed densities was resulted due to increase in severity of weed competition stress. The enhanced utilization of essential growth factors by increasing densities of jungle rice and false amaranth deprived rice crop from these that resulted in greater loss in rice grain yield. Babu (2012) reported a decrease in yield ranging from 48 to 86% with the increased densities (from 50 to 400 plants m^{-2}) of jungle rice, whereas weed-free control gave the maximum paddy yield. Mehmood *et al.* (2018) declared rice yield losses ranging from 21-23% with increasing densities of alligator weed. Subbaiah (2008) also mentioned a statistically significant decline in paddy yield in DSR when the density of jungle rice was increased from its 2 to 6 weed plants m^{-2}. Our research findings coincide with conclusions of Tomado *et al.* (2002) that percent reduction in grain yield of sorghum occurred by an elevated population of parthenium weed. The current findings are also in coincidence with those of Al-Mamun *et al.* (2013) who recorded the highest (8.52 & 7.08 t ha^{-1}) paddy yield in weed free plots while the lowest (5.76 t ha^{-1} & 6.16 t ha^{-1}) by a density of 80 weed plants m^{-2}. Karim and Firdous (2010) pointed out reduction in the paddy yield by 2.66 to 54% due to the infestation of *E. indica* at its density of 28 to224 plants / m^2, respectively. A seed yield reduction of chickpea (18-53%) and soybean (12-30%) was reported by Mishra and Singh (2003) due an incline in the densities of *E. geniculate* from10 to 20 weed plants / m^2 in soybean-chickpea cropping sequence.

Al-Mamun *et al.* (2013) also unveiled the highest (8.52 t ha^{-1}) paddy yield in control plots while a minimum (5.76 t ha^{-1}) paddy yield from 80 plants (m^{-2}) of weeds. Karim and Firdous (2010) pointed out a reduction of paddy yield up to 2.66, 12.59, 44.93 and54.01% at *Echinochloa* densities of 28, 56, 144, and 224 m^{-2}, respectively. Babu (2012) also reported maximum grain yield of rice in the treatment without any weed. Our revelations are similar to those of Mehmood *et al.* (2018) that declared a rice yield loss ranging from 21.37-23.78% with increasing densities of alligator weed and reported ETLs of alligator weed as 1.5 and 1.3 plants / m^2, in two successive years study. Yu *et al.* (2007) also registered a loss in paddy yield (43-50%) with the increasing densities (23 to 180 plants m^{-2}) of *A. philoxeroides* where 100 rice plants were present in an area of one-meter square. Sultana (2000) also declared a loss in rice grain yield ranging from 51-64% in treatment where a density of 100-200plants $m^{-2}$of *Echinochloa crus-galli* was maintained in comparison with weed-free plots in DSR. Karim and Firdous (2010) also pointed out a reduction in the paddy yield by 2.66, 12.59, 44.93 and 54.01% due to the infestation of *E. indica* in treatments with its population of 28, 56, 144 and 224 plants m^{-2}, respectively. Babu (2012) also reported a decrease in yield from 48 to 86% with the increased densities of jungle rice from 50 to 400 plants m^{-2}, whereas the highest paddy yield was attained from weed-free treatment. Subbaiah (2008) also mentioned a statistically significant decline in paddy yield under DSR conditions when the density of jungle rice was increased from its 2 to 6 weed plants m^{-2}.

CONCLUSIONS

It can be concluded that the jungle rice and false amaranth should be controlled when their plant densities surpassed 2.2-2.8 and 1.4-1.6 plants m^{-2}, respectively to avoid economic loss.

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REFERENCES

Aamer, I and Z.A. Cheema. 2006. Comparative efficiency of barnyard grass and rice to nitrogen under transplanted condition. J. Trop. Agri. Food Sci. 34(2):385-392.

Al-Mamun, M. A., R. Shultana, B. C. Roy, A. Parvez and A. J. Mridha. 2013. Determination of yield loss and economic threshold density of *Scirpus maritimus* in winter rice. Academia J. Agri. Res., 1(11):211-219.

Al-Mamun, M. A. 2014. Modelling rice-weed competition in direct-seeded rice cultivation. Agric. Res., 3(4):346-352.

Ashraf, M. M., T. H. Awan, Z. Manzoor, M. Ahmad and M. E. Safdar 2006. Screening of herbicides for weed management in transplanted rice. J. Anim. Plant Sci., 16(4):89-92.

Babu, M. B. B. P. 2012. Impact of varying densities of jungle rice on rice productivity. Indian J. Weed Sci., 44(1):43-45.

Begum, M., A. S. Juraimi, R. Amartalingum, S. R. Omar and A. B. Man 2009. Effect of *Fimbristylis miliacea* competition with MR-220 rice in relation to different nitrogen levels and weed density. Int. J. Agri. Biol., 11(2):183-187.

Blackshaw, R. E., H. J. Beckie, L. J. Molnar, T. Entz and J.R. Moyer. 2005. Combining agronomic practices and herbicides improves weed management in wheat–canola rotations within zero-tillage production systems. Weed Sci., 53(4):528-535.

Chauhan, B. S. and D.E. Johnson 2011. Growth response of direct-seeded rice to oxadiazon and bispyribac-sodium in aerobic and saturated soils. Weed Sci., 59(1):119-122.

Chauhan, B. S. 2012. Weed ecology and weed management strategies for dry-seeded rice in Asia. Weed Technol., 26(1):1-3.

Cortés, J. A., M. A. Mendiola and M. Castejón. 2010. Competition of velvetleaf (*Abutilon theophrasti* M.) weed with cotton (*Gossypium hirsutum* L.). Economic damage threshold. Spanish J. Agric. Res., 8(2):391-399.

Cousens, R. 1985. A simple model relating yield loss to weed density. Ann. Appl. Biol., 107(2):239-252.

Cousens, R. 1987. Theory and reality of weed control thresholds. Plant Prot., Quart. 2:13-20.

FAO 2011. Global cereal supply and demand brief. Food and Agricultural Organization, Rome, Italy.

Farooq, M., K. H. Siddique, H. Rehman, T. Aziz, D. L. Lee and A. Wahid. 2011. Rice direct seeding: experiences, challenges and opportunities. Soil Till. Res., 111(2):87-98.

Government of Pakistan. 2020. Economic Survey of Pakistan 2019-2020. Economic Adviser’s Wing, Finance Division, Govt. Pakistan, Islamabad.

Government of Pakistan 2015. Economic Survey of Pakistan 2014-2015. Economic Adviser’s Wing, Finance Division, Govt. Pakistan, Islamabad.

Gwon, O. D, H. Y. Kim, B. C. Mun, Y. L. Guk and J. G. Kim. 2006. Effect of densities of *Echinochlor crus-galli* and *Monochoria vaginalis* in wet seeding and transplanting rice cultivation on rice yield and rice quality, and economic threshold levels of the weeds. Korean J. Weed Sci., 26(2):155-167.

Hussain Z, K. B. Marwat and J. Cardina. 2011. Common cocklebur competition in forage maize. Weed Technol., 25(1):151-158.

Islam, M. F., S. R. Karim, S. M. A. Haque, M. S. Islam and M. S. Islam 2003. Effect of population density of *Echinochloa crus-galli* and *Echinochloa colonum* on rice. Pak J. Agron., 2(3):120-125.

Kankal, V. Y. 2015. Effect of establishment techniques, weed control and integrated nutrient management on growth, yield and quality of drilled rice (*Oryza sativa* L.). Ph.D. (Agri.) Thesis (unpublished). Deptt. of Agronomy, Dr. B.S.K.K.V. Dapoli, India (M.S.).

Karim, S. M. R and M.N. Ferdous. 2010. Density effects of grass weeds on the plant characters and grain yields of transplanted Aus-rice. Bangladesh J. Weed Sci., 1(1):49-54.

Khaliq, A and A. Matloob. 2011. Weed-crop competition period in three fine rice cultivars under direct-seeded rice culture. Pak J. Weed Sci. Res., 17(3):229-243.

Khan, T. A. and M. H. Tarique. 2011. Effects of weeding regime on the yield and yield contributing characters of transplant Aman rice. Int. J. Sustain Agri. Tech., 7(11):11-14.

Kumar, V. and J. K. Ladha. 2011. Direct seeding of rice: recent developments and future research needs. In Advances in Agronomy. 111:297- 413. Academic Press.

Kwon, O. D., S. H. Cho, B. C. Moon and Y. I. Kuk. 2007. Effect of densities of *Echinochloa crus-galli* and *Cyperus difformis* in transplanting rice cultivation on rice yield and rice quality, and economic threshold levels of the weeds. Korean J. Weed Sci., 27(2):102-111.

Mandal, D., D. Singh, R. Kumar, A. Kumari and V. Kumar. 2011. Effects on production potential and economics of direct seeded rice sowing dates and weed management techniques. Indian J. Weed Sci., 43(3):139-144.

Mann, R. A. and M. Ashraf. 2001. Improvement of Basmati and its production practices in Pakistan. In: Specialty of the World. p.129-148.

Mehmood, A., A. Tanveer, M. M. Javed, M. A. Nadeem, M. Naeem and T. Abbas. 2018. Estimation of economic threshold level of alligator weed (*Alternanthera philoxeroides* (Mart.) Griseb.) to tackle grain quality and yield losses in rice. Arch. Agron. Soil Sci., 64(2):208-218.

Mishra, J. S., V. P. Singh and N.T. Yadira. 2006. Wild onion (*Asphodelus tenuifolius* Cav.) interference in lentil and chickpea crops and its management through competitive cropping. Weed Biol. Manag., 6(3):151-156.

Mishra, J. S. and V. P. Singh. 2003. Interference of *Euphorbia geneculata* in soy bean-chick pea cropping system. Indian J. Weed Sci., 35 (3):225-227.

Moon, B. C., J. G. Won, Y. L. Kim, S. W. Kim, I. Y. Lee and J. Eup. 2011. Prediction of rice yield loss from rice-*A. indica* (*Aeschynomeme indica* L.) competition in transplanted rice cultivation, Proc. 23rd Asian-Pacific Weed Science Society Conference. p. 97.

Morales-Payan, J. P. 2000. Interference of increasing *Parthenium hysterophorus* L. population densities with tomato (*Lycopersicon esculentum* Mill.), Proc. 3rd International Weed Science Congress. p. 73.

Nahar. S., M. A. Islam and M. A. R. Sarkar. 2010. Effect of spacing and weed regime on the performance of transplant Aman rice. Bangladesh J. Weed Sci., 1(1):89-93.

Nadeem, M.A., B.A. Jan, S. Afzal, M.A. Khan, T. Abbas, M.M. Javaid, M.M. Amin, N. Farooq and A. Aziz. 2020a. Effect of aqueous extract of *Carthamus tinctorius* L. on germination and initial seedling growth of *Oryza punctata* L. Pak. J. Weed Sci. Res., 26(3): 331-342.

Nadeem, M.A., B.A. Khan, S. Afzal, A. Aziz, R. Maqbool, M.M Amin, A. Aziz, A. Ali, M. Adnan and Durrishahwar. 2020b. Allelopathic Effects of aqueous extracts of *Carthamus tinctorius* L. on emergence and seedling growth of *Echinochloa crus-galli* L. Pak. J. Weed Sci. Res., 26(3): 365-379.

Rao, A. N., D. E. Johnson, B. Sivaprasad, J. K. Ladha and A. M. Mortimer. 2007. Weed management in direct seeded rice. Adv. Agron., 93:153-255.

Revathi, A. (2009). Establishment techniques and weed management practices in puddled lowland rice. M.Sc. (Ag.) Thesis. Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India.

Saqib, M., N. A. Ehsanullah, M. Latif, M. Ijaz, F. Ehsan and A. Ghaffar.

2015. Development and appraisal of mechanical weed management strategies in direct- seeded aerobic rice (*Oryza sativa L.*). Pak J. Agri. Sci., 52(3):587-93.

Safdar, M. E., A. Tanveer, A. Khaliq and M. A. Riaz. 2015. Yield losses in maize (*Zea mays*) infested with parthenium weed (*Parthenium hysterophorus* L.). Crop Prot., 70:77-82.

Singh, S., L. Bhushan, J. K. Ladha, R. K. Gupta, A. N. Rao and B. Sivaprasad. 2006. Weed management in dry-seeded rice (*Oryza sativa* L.) cultivated in the furrow-irrigated raised-bed planting system. Crop Prot., 25(5):487-495.

Singh, S., J. K. Ladha, R. K. Gupta, L. Bhushan and A. N. Rao. 2008. Weed management in aerobic rice systems under varying establishment methods. Crop Prot., 27(5):660-671.

Singh, T., J. S. Kolar and K. S. Sandhu. 1991. Effect of variable densities of wrinkle grass (*Ischaemum rugosum* Salisb.) on growth and yield of transplanted paddy. Indian J. Weed Sci., 23(4):72-75.

Smith, R. G., L. W. Atwood, F. W. Pollnac and N. D. Warren. 2015. Cover-crop species as distinct biotic filters in weed community assembly. Weed Sci., 63(1):282-295.

Steel, R. G. D., J. H. Torrie and D. A. Dickey 1997. Principles and Procedures of Statistics. A Biometrical Approach 3rd Ed. McGraw Hill Book Co., Inc. Singapore, p.172-177.

Subbaiah, S. V. 2008. Studies on weed water management in direct-seeded rice. In: Singh, Y., V.P. Singh, B. Chauhan, A. Orr, A.M. Mortimer, D.E. Johnson, B. Hardy, (eds). Direct-seeding of rice and weed management in irrigated rice-wheat cropping system of the Indo-Gangetic Plains. Los Banos (Philippines): International Rice Research Institute and Pantnagar (India): Directorate of Experiment Station, G. B. Pant University of Agriculture and Technology, p.177-189.

Sultana, R. 2000. Competitive ability of wet-seeded boro-rice against *Echinochloa crusgalli* and *Echinochloa colonum*. MSc. thesis. Bangladesh Agricultural University.

Tabbal, D. F., B. A. Bouman, S. I. Bhuiyan, E. B. Sibayan and M. A. Sattar. 2002. On-farm strategies for reducing water input in irrigated rice; case studies in the Philippines. Agric. Water Manag., 56(2):93-112.

Tian, Z., G. Shen, G. Yuan, K. Song, J. Lu and L. Da (2020). Effects of *Echinochloa crusgalli* and *Cyperus difformis* on yield and eco-economic thresholds of rice. J. Cleaner Prod., 120807.

Tomado, T., P. Ohlander and P. Milberg. 2002. Interference by the weed *Parthenium hysterophorus* L. with grain sorghum: Influence of weed density and duration of competition. Int. J. Pest Manag., 48(3):183-188.

Tuong, T. P. and B. A. Bouman. 2003. Rice production in water-scarce environments. Water Productivity in Agriculture: Limits and Opportunities for Improvement: 13-42.

Yu, L. Q., Y. Fujii, Y. J. Zhou, J. P. Zhang, Y. L. Lu and S. N. Xuan. 2007. Response of exotic invasive weed *Alternanthera philoxeroides* to environmental factors and its competition with rice. Rice Sci., 14(1):49-55.