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Estimation of the economic threshold of *Leptochloa chinensis* (Chinese sprangletop) in direct-seeded fine grain rice (*Oryza sativa*)

Estimativa do limiar econômico de *Leptochloa chinensis* (chinese sprangletop) em arroz de grão fino (*Oryza sativa*) em semeadura direta

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Highlights

Impact of *L. chinensis* density on growth and yield performance of direct seeded rice.
Reduction in economic yield of rice due to *L. chinensis* were investigated.
Economic threshold of *L. chinensis* in DSR were estimated by using cousens modle.
L. chinensis must be controlled at 1.73 and 1.70 plant m^{-2} to avoid yield losses.

Abstract

Leptochloa chinensis (L.) Nees (Chinese sprangletop) is a weed that is becoming a serious threat in upland and lowland rice. A field study was conducted at the Agronomic Research Farm, University of Sargodha, Punjab, Pakistan, during the summer seasons of 2018 and 2019 to evaluate the effect of *L. chinensis* density on the yield of direct-seeded fine rice. Treatments comprised of *L. chinensis* densities of 0, 5, 10, 15, 20 and 25 plants m^{-2}, and the experiment was laid out in a randomized complete block design with four replications of each treatment. The results suggest that the presence of *L. chinensis* significantly hampered the grain yield of direct-seeded rice. Weed infestation caused 63% and 69% yield losses where 25 L. chinensis plants m^{-2} were sustained in 2018 and 2019, respectively. Yield reduction was due to the reduction in 1000-grain weight (22.9 and 29.1%), number of tillers m^{-2} (65.8 and 60.0%), and number of grains panicle^{-1} (53.3 and 60%) in 2018 and 2019, respectively. The highest weed infestation (25 plants

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m^{-2}) produced the highest weed dry biomass (687 and 669 g m^{-2}), N uptake (19.3 and 19.3 kg ha^{-1}), P uptake (1.92 and 2.32 kg ha^{-1}), and K uptake (20.53 and 20.27 kg ha^{-1}) in 2018 and 2019, respectively. The lowest weed infestation (5 plants m^{-2}) produced minimum weed dry biomass (47 and 85 g m^{-2}), N uptake (1.6 and 2.9), P uptake (0.3 and 0.5), and K uptake (1.7 and 30 kg ha^{-1}) in 2018 and 2019, respectively. The economic threshold of *L. chinensis* as estimated to cause 6.73% and 6.08% yield loss by the prediction model was 1.70 and 1.73 plants m^{-2} during 2018 and 2019, respectively. It can be concluded that *L. chinensis* is a serious weed in direct-seeded rice and it should be controlled when its density reaches 1.70-1.73 plants m^{-2} to avoid significant yield losses.
Key words: Economic threshold. Densities. Design. Weed. Competition.

Resumo

Leptochloa chinensis (L.) Nees (chinese sprangletop) é uma planta daninha que está se tornando uma séria ameaça no arroz de terras altas e baixas. Um estudo de campo foi realizado na Fazenda de Pesquisa Agronômica, Universidade de Sargodha, Punjab, Paquistão, durante as estações de verão de 2018 e 2019 para avaliar o efeito da densidade de *L. chinensis* na produção de arroz fino de semeadura direta. Os tratamentos foram compostos por densidades de *L. chinensis* de 0, 5, 10, 15, 20 e 25 plantas m^{-2}, e o experimento foi delineado em blocos casualizados com quatro repetições de cada tratamento. Os resultados sugerem que a presença de *L. chinensis* prejudicou significativamente a produtividade de grãos do arroz de semeadura direta. A infestação de ervas daninhas causou perdas de rendimento de 63% e 69%, onde 25 plantas de *L. chinensis* m^{-2} foram mantidas em 2018 e 2019, respectivamente. A redução da produtividade deveu-se à redução no peso de mil grãos (22,9 e 29,1%), número de perfilhos m^{-2} (65,8 e 60,0%) e número de panículas^{-1} (53,3 e 60%) em 2018 e 2019, respectivamente. A maior infestação de plantas daninhas (25 plantas m^{-2}) produziu a maior biomassa seca de plantas daninhas (687 e 669 g m^{-2}), absorção de N (19,3 e 19,3 kg ha^{-1}), absorção de P (1,92 e 2,32 kg ha^{-1}) , e absorção de K (20,53 e 20,27 kg ha^{-1}) em 2018 e 2019, respectivamente. A menor infestação de plantas daninhas (5 plantas m^{-2}) produziu biomassa seca mínima de plantas daninhas (47 e 85 g m^{-2}), absorção de N (1,6 e 2,9), absorção de P (0,3 e 0,5) e absorção de K (1,7 e 30 kg ha^{-1}) em 2018 e 2019, respectivamente. O limiar econômico de *L. chinensis* estimado para causar perda de rendimento de 6,73% e 6,08% pelo modelo de previsão foi de 1,70 e 1,73 plantas m-2 durante 2018 e 2019, respectivamente. Pode-se concluir que *L. chinensis* é uma planta daninha importante em arroz de semeadura direta e deve ser controlada quando sua densidade atingir 1,70-1,73 plantas m^{-2} para evitar perdas significativas de produtividade.
Palavras-chave: Limite econômico. Densidades. Design. Erva. Competição.

Introduction

Rice is one of the most important cereals in the world, after wheat, and is a staple food for more than half of the world's population (Xu et al., 2021). In Pakistan, it is cultivated in an area of 3.3 million ha with a total production of 8.4 million tons and an average yield of 2,524 kg ha^{-1} (GOP, 2021). Conventionally, rice is grown in a nursery and then transplanted into puddled or flooded field conditions after a month (Ehsanullah, Jabran, & Habib, 2007). This strategy not only adequately restrains rice weeds by preventing light from penetrating the stagnant water layer, but also provides the rice plants with a superior growing environment (Chauhan & Johnson, 2011; Farooq et al., 2011). However, the labor requirement, water scarcity, nursery rearing, transplanting, and weeding all lead to a high cost to grow rice with traditional methods. Additionally, puddling in conventional methods disperses the soil particles and makes the soil compact thereby threatening the sustainability of the system (Singh et al., 2002). Future water shortage projections have predicted that by 2025, about 2 Mha of irrigated rice fields in Asia will suffer from water deficiency during the dry season, particularly as flood-irrigated rice uses more than 45% of the total freshwater used for agricultural purposes (Bouman, 2001). Therefore, several agricultural strategies such as direct-seeded rice (DSR) have been developed and practiced to produce more rice, increase water use efficiency, and reduce water input in the fields (Bouman, Peng, Castaneda, & Visperas, 2005).

DSR innovation is gradually gaining favor with farmers as it saves water and reduces production costs. In addition, DSR allows for early sowing of wheat crop, reduces methane emission, and ensures the greatest benefit to regions with an assured water supply (Kumar & Ladha, 2011). However, competition between crops and weeds in this framework is more extreme, reducing the yield by 20-95% (Balasubramanian & Hill, 2002; Gogoi, Rajkhowa, & Kandali, 2000). There is, surprisingly, little literature on the differential response of rice with different weed densities in DSR, probably as a result of the complexities associated with weed intensity. A few studies suggest that the planting densities of 5, 108, and 215 plants m^{-2} of red rice (*Oryza punctata*) reduced rice yield by 22, 66 and 82% (Diarra, Smith, & Talbert, 1985). Similarly, an increase of weed density m^{-2} reduced the number of grains $panicle^{-1}$, number of panicles m^{-2}, 1000-grain weight, and grain yield of rice (Al Mamun, Shultana, Rana, & Mridha, 2013). Moreover, unrestrained weeds reduced rice yield by up to 40% in South Korea (Kim & Ha, 2005), 30% in Bangladesh (BRRI, 2006) and 36% in the Philippines (Rao & Moody, 1992). DSR is subjected to diverse weed intensity compared to conventional waterlogged methods, as the alternating wetting and drying conditions are conducive to weed germination and growth, resulting in reduced economic yield loss of approximately 50-91% (Fujisaka, Moody, & Ingram, 1993).

Leptochloa chinensis is a common weed in direct-seeded rice (Chauhan & Johnson, 2011). Its ability to withstand moist, drained or waterlogging conditions allows it competes with crop plants during the active growth period. *L. chinensis* has become more prevalent within a few years of adopting DSR and in wet sown rice (Allard, Pradith, & Kotzian, 2005). It is a native of tropical Asia, where it is usually found in water channels and rice field. Now it is widespread in Australia, Papua New Guinea, and West Africa. Usually it is produced by the seed as well as reproduced vegetatively by rootstocks. Importance of *L. chinensis* has increased with a shift of sowing method of rice from transplanted to direct sown (Pane, Mansor, & Watanabe, 1996). Apparently, it cannot germinate under 5 cm of water but can germinate in saturated soil conditions. Hence it is able to germinate and establish successfully along with direct seeded rice. Each inflorescence of *L. chinensis* has capability to produce hundreds of seeds, a plant may have numbers of inflorescence (Holm, Plucknett, Pancho, & Herberger, 1977). Fresh seeds of *L. chinensis* can give 61% germination within 8 weeks of shedding and are found to be sensitive to light and all seeds germinate in moist soil condition at 30-40ºC (Benvenuti, Dinelli, & Bonetti, 2004).

L. chinensis is a strongly tufted annual grass of aquatic and semiaquatic conditions, and is known to be invasive (Manidool, 1992). The invasive capability of this species has been connected to its high seed production (Chin, 2001). *L. chinensis* is listed as a federal noxious weed in the USA (Westbrooks, 1991), resistant to some rice herbicides, for instance bentazone and quinclorac, yet susceptible to most others, including butachlor, fenoxaprop, molinate, pretilachlor and thiobencarb (Ampong-Nyarko & de Datta, 1991). Similarly, Chauhan, Abeysekara, Kulatunga, and Wickrama (2013) stated that herbicides pretilachlor plus pyribenzoxim, cyhalofop-butyl, thiobencarb plus propanil, propanil, and bispyribac-sodium plus metamifop used against barnyardgrass, Chinese sprangletop, and knotgrass provide similar results ranged from 82 to 99% weed control in DSR. The competitiveness of *L. chinensis* is high due because it is a C_4 plant and more proficient photosynthesis results in increased rate of biomass production. Knowing the extent to which *L. chinensis* and rice may behave in DSR is of practical relevance for the management of *L. chinensis* in direct-seeded rice. Therefore, keeping in view the importance of *L. chinensis* and its increasing infestation in DSR crops, the current study was proposed to investigate the economic threshold of *L. chinensis* in direct-seeded fine grain rice.

Materials and Methods

Plant material and research site

A field experiment was conducted during the summer seasons of 2018 and 2019 at the research area of the Agronomy Department, College of Agriculture, University of Sargodha, Sargodha, Pakistan (31.32°N and 71.8°E and at 190 m altitude). Wheat was sown in this research area prior to the start of the present study. A field trial was conducted to evaluate the impact of various densities of *L. chinensis* (0, 5, 10, 15, 20, 25 weeds m^{-2}) on the growth and yield performance of DSR and economic threshold density during 2018 and 2019. The experiment was laid out in a randomized complete block design (RCBD) and each treatment was replicated four times. The experiments of both years were laid out in a randomized complete block design and replicated four times. Net plot size was 4 m × 2 m.

Soil characteristics and weather description

Soil samples from depths of 0–15 and 15–30 cm were taken before planting. Five examples were gathered at every depth randomly and then combined to one sample. The pH meter was utilized for the assurance of soil pH. N was dictated by Ginning and Hibbard's strategy for H_2SO_4 digestion, and refining was made with macro Kjeldhal's apparatus (Jackson, 1962). The accessible P in the soil was dictated by the Olsen strategy (Sims, 2000). The potassium content of the filtered extract was determined by using a flame photometer. The analysis of soil was presented in Table 1. From 0 cm to 30 cm soil profundities, soil pH and organic matter ran between 7.75 to 7.85 and 0.72 to 0.73%, respectively. However, the amount of N was low and P and K were medium in the soil of the experimental site (Table 1). Maximum and minimum day to day temperature and precipitation during the study was noted (Figure 1).

Table 1
Physicochemical analysis of soil

Characteristics	Unit	Year			
		2018		2019	
		0-15 cm	15-30 cm	0-15 cm	15-30 cm
Soil pH	-	7.7	7.8	7.8	7.9
Electrical conductivity	dS m^{-1}	1.73	1.80	1.76	1.79
Organic matter	%	0.90	0.55	0.93	0.53
Total N	%	0.043	0.039	0.045	0.040
Available P	%	8.4	4.1	8.5	4.2
Available K	ppm	162	148	165	155
Texture	-	Loam		Loam	

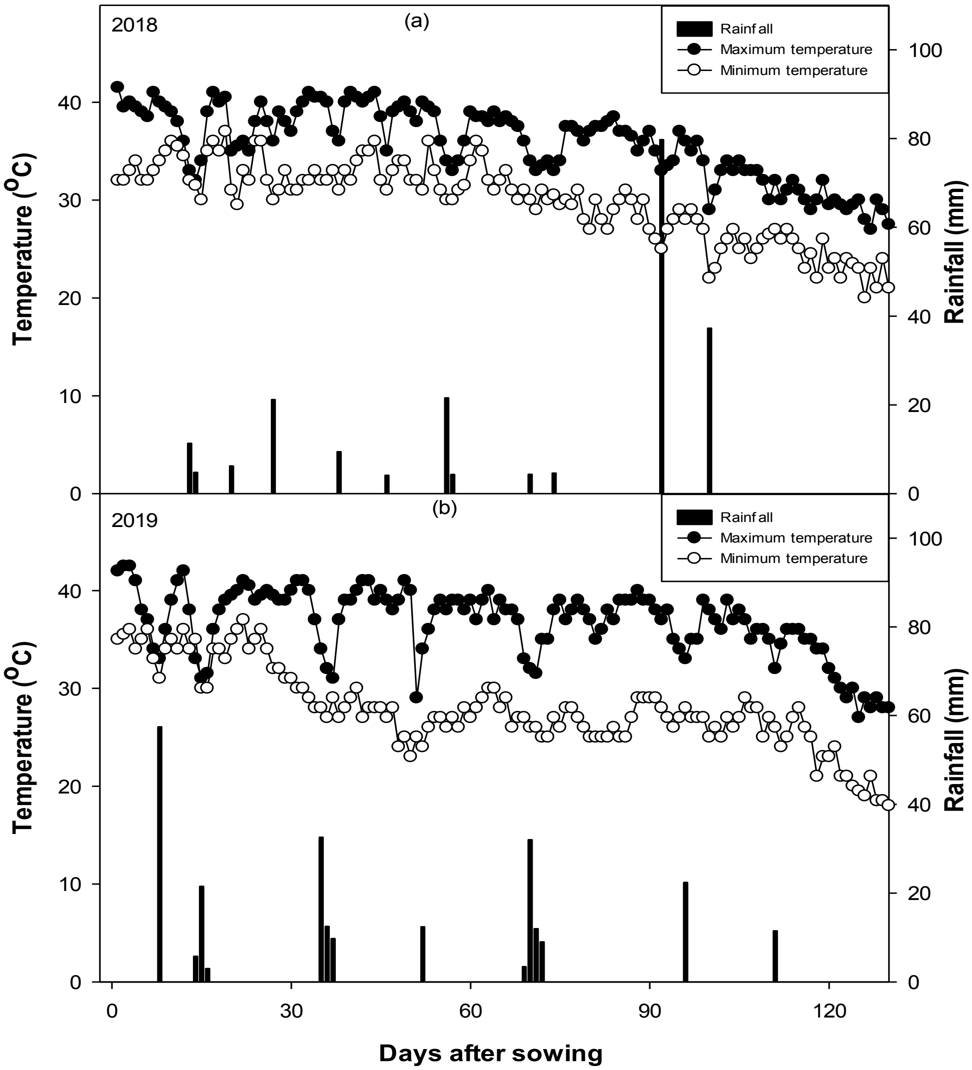

Figure 1. Metrological data during the growing season of the years 2018 and 2019.

Crop husbandry

After wheat crop harvesting from the field, the seedbed was prepared by cultivating (30 cm deep) the soil 2-3 times, followed by planking by using tractor. Fine paddy cultivar "super basmati" was sown on the 28th of June 2018 and the 26th of June 2019. Seeds were soaked for 8 hours and then sown by using a hand drill in dry soil conditions, maintaining row distance of 25 cm apart with seed rate of 35 kg ha^{-1}, irrigation was done just after sowing. After irrigation, seeds of *L. chinensis* having 90% germination were manually broadcasted in the field. The N, P and K fertilizers were broadcasted at the rate of 200, 150 and 125 kg ha^{-1} respectively as urea (46%), di-ammonium phosphate (46% P and 18% N) and potassium as sulphate of potash (50%). A full dose of phosphorus and potassium, and one third dose of nitrogen were applied at time of sowing. The remaining 2nd dose was applied 30 days after sowing at Tillering stage and a 3rd was applied at the flowering stage. After weed germination, all other weeds were uprooted manually after 3 days, except *L. chinensis*, and its density was maintained during the whole crop growth period. Irrigation was applied as per the requirement of the crop. At physiological maturity, crop was harvested and weed data (weed fresh weight, weed dry weight, NPK contents %, and NPK uptake) were collected (all weed plants from each treatments was uprooted and weight was taken 95 days after emergence of weed these plants were subjected to oven dry at 70°C till constant weight for getting dry weight) and crop data (plant height, number of plant m^{-2}, spike length, number of grain $spike^{-1}$, 1000-grain weight, economic yield, and biological yield) were recorded by using standard methods. Harvest index was calculated by the following formula:

$$\text{Harvest index (\%)} = \frac{Economic\ yield}{Biological\ yield} \times 100$$

Economic yield (kg ha^{-1})

After the harvesting and threshing of whole plot, their grains yield $plot^{-1}$ was recorded (moisture content 14%) by using electrical field balance in Kilogram. Then the grain yield Kg $plot^{-1}$ was converted to kg ha^{-1}.

Biological yield (kg ha^{-1})

Whole plot was harvested at maturity (un-threshed) tied and then weight by means of electrical field balance to get biological yield kg $plot^{-1}$ and then converted into kg ha^{-1}.

Determination of NPK

Dried samples of the mature plants of *L. chinensis* (whole plant) were ground by using an electric grinder. Then 1 g of ground-sample from each treatment was mixed with 10 ml of H_2SO_4 and left overnight in a conical flask. Then 5 ml of H_2O_2 was added and put onto a hot plate that was heated slowly until the digest (sample) was clear. Then the digested sample was diluted to 50 ml and stored in labeled plastic bottles for further processing. For N determination, 10 ml aliquots were drawn from the sample for the distillation of ammonia in the presence of 40% NaOH by using a micro-Kjeldhals apparatus. Nitrogen was collected in the form of ammonia in a receiver of micro-Kjeldhal apparatus, having a 4% solution of boric acid, alongside indicators (Methyl red and Bromocresol green) and titration was performed against 0.1N H_2SO_4. Phosphorus was determined by using a spectrophotometer (Beckman) and potassium was determined by using a flame photometer (Jenuary 8505).

Statistical analysis

Collected data were subjected to analysis according to Fisher's analysis of variance and means were compared by least significant difference by using statistix 8.1 (Analytical Computer Software, 2005) at 5% probability (Steel et al., 1997). In the combined year analysis, the year effect was found to be significant, therefore the data of two years were analyzed separately. Trend analysis was done to see the linear, quadratic, and cubic reaction of weed and crop parameters to different *L. chinensis* densities. A rectangular, non-linear hyperbolic regression model (Cousens, 1985) was fitted to the rice grain yield data (Y) and L. chinensis density (d). The model equation is

$$Y = \frac{Yo}{1 + \beta x}$$

Where, Y is simulated rice yield (kg ha^{-1}) at a particular density, Y_o is weed-free rice yield (kg ha^{-1}), β is a measure of weed competitivity (a weed density of 1/β reduces the rice yield by 50%), and x = *L. chinensis* weed density.

To analyze the relationship between the paddy yield loss (YL) and the *L. chinensis* density (D). The model equation was as follows:

$$\mathrm{YL} = \frac{i \times D}{1 + \frac{i \times D}{A}}$$

Where YL is the percentage of paddy yield loss due to *L. chinensis*, i is the percentage of yield loss per unit of weed density (D) as D → 0, A is the asymptotic value of the maximum yield loss (%), as D → ∞. Parameter estimates were determined for the model using nonlinear regression techniques.

The economic threshold (ET) of *L. chinensis* was assessed by equating the expense of controlling this weed with the value of rice yield acquired by herbicide application. Their calculation was based on the following equation developed by Cousens, (1987).

$$ET = (Ch + Ca)/YoPLH)$$

Where, Ch is herbicide cost (PKR ha^{-1}), Ca is application cost (PKR ha^{-1}), Yo is weed-free rice yield (kg ha^{-1}), P is value per unit of the crop (PKR kg^{-1}), L is proportional loss per unit weed density, and H is herbicide efficacy (a proportional reduction in weed density or weed biomass by the herbicide treatment). The prices of herbicide and paddy was defined as per market value at time of experiments for the year 2018 and 2019.

Results and Discussions

Weed fresh and dry weight

Data exhibited that fresh and dry biomass of weed increased by the increase of densities from 5 to 25 plants m^{-2} in a rectilinear fashion (Table 2). The lowest fresh and dry biomass (113 and 47 g m^{-2} in 2018, and 128 and 85 g m^{-2} in 2019) was recorded with 5 plants m^{-2}, and the maximum fresh and dry biomass was observed with 25 plants m^{-2} (1594 and 687 g m^{-2} in 2018 and 1695 and 669 g m^{-2} in 2019). Analysis of weed fresh and dry weight showed a cubic trend in response to increasing weed density. The increase of weed biomass appears, due to the addition of biomass of 5 weed plants in each sequential density level. Due to a higher weed density, this plants compete with crop plants and grow quickly as compared to rice plants, producing maximum dry weight.

Also, Bhagat and Black (1999) noted that dominance of *Echinochloa crus-galli* and *L. chinensis* was favored by the saturated soil condition. In our study, different densities of *L. chinensis* significantly affected the growth and yield of direct-seeded rice. The *L. chinensis* produced higher dry biomass at higher weed infestation, potentially due to quick growth and efficient competition with rice plant. Furthermore, the increase in dry biomass of *L. chinensis* was not proportional to increase in its density. The increase in density was fivefolds (from 5 to 25 plant m^{-2}), but increase in dry biomass was almost fifteen fold (from 47 to 687 g m^{-2}).

Table 2
Biomasses (Fresh weight, dry weight) and NPK uptakes of L. chinensis at its different densities in direct seeded rice

Density (Plants m^{-2})	Weed fresh weight (g m^{-2})		Weed dry weight (g m^{-2})		Nitrogen uptake (kg ha^{-1})		Phosphorous uptake (kg ha^{-1})		Potassium uptake (kg ha^{-1})	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
0	0 e	0 f	0 e	0 e	-------	-------	------	-------	-------	-------
5	113 d	128 e	47 d	85 d	1.6 d	2.9 d	0.3 d	0.5 d	1.7 d	3.0 d
10	181 cd	206 d	77 cd	92 d	2.4 cd	3.1 d	0.4 cd	0.6 cd	2.6 cd	3.2 d
15	287 c	325 c	117 c	140 c	3.6 c	4.3 c	0.6 c	0.7 c	3.8 c	4.7 c
20	626 b	761 b	271 b	344 b	8.1 b	10.2 b	1.1 b	1.4 b	8.7 b	11.2 b
25	1594 a	1695 a	687 a	669 a	19.3 a	19.3 a	1.9 a	2.3 a	20.5 a	20.3 a
LSD	107.46	26.50	42.24	18.81	1.30	0.62	0.15	0.11	1.43	0.62
Trend comparison										
Linear	**	**	**	**	**	**	**	**	**	**
Quadratic	**	**	**	**	**	**	**	**	**	**
Cubic	**	**	**	**	**	**	NS	**	**	NS

Means values that were followed by the same letter did not differ significantly at the 5% probability level, ** significant at 1% probability level, NS = non-significant.

Similarly, dry biomass of *Lolium rigidum* (Izquierdo i Figarola, Recasens i Guinjuan, Fernández-Quintanilla, & Gill, 2003), *Emex australis* (Abbas, Tanveer, Ali, & Zaheer, 2010), and *Scirpus maritimus* (Al Mamun et al., 2013) followed the linear pattern of increase in dry weight. An increasing trend of weed dry biomass was also reported by

Mishra, Singh, and Yaduraju (2006). Similar results also reported by Mahajan, Chauhan, and Johnson (2009) stated that stating that the dry matter of grassy weeds was 28.3% higher in DSR when contrasted with a traditional technique for rice planting. A reduction in the dry biomass of individual plants, probably related to intraspecific and interspecific competition at higher densities, might be responsible (Zimdahl, 2007). In contrast, decrease in dry biomass of single plants with increasing density was most likely correlated to intraspecific and interspecific competition at higher densities (Hazra, Das, & Yaduraju, 2011).

NPK uptake by L. chinensis

Data related to NPK uptake were presented in Table 2. Maximum N uptake (19.3 and 19.3 kg ha^{-1}), P uptake (1.9 and 2.3 kg ha^{-1}), and K uptake (20.5 and 20.2 kg ha^{-1}) was calculated from the treatment that was sustained 25 weeds m^{-2} throughout the cropping period in 2018 and 2019, respectively. Similarly, the minimum N uptake was recorded (1.6 and 2.9 kg ha^{-1}), P uptake (0.3 and 0.5 kg ha^{-1}) and K uptake (1.7 and 3.0 kg ha^{-1}) from treatment that had 5 plants m^{-2} in 2018 and 2019. In trend comparison, linear, quadratic, and cubic trends were shown to be significant for N uptake in 2018 and 2019, P uptake in 2019, and K uptake in 2018, while linear and quadratic trends were observed to be significant for P uptake in 2018 and K uptake in 2019. N, P, and K uptake by *L. chinensis* was increased with increasing *L. chinensis* density due to an increase in competition between crop and weed. Similar results were also reported by (Abbas et al., 2010; T. Singh & Kolar, 1993) who stated that wrinkle grass removed 74 kg N, 6 kg P and 108 kg K ha^{-1}. Barnyard grass in a density of 16 plant m^{-2} removed 180 kg N ha^{-1}. These outcomes were also confirmed by NAM-IL, Ogasawara, Yoneyama, and Takeuchi (2001) who reported that removal of NPK from soil was increased with the increase in density of annual bluegrass and creeping bentgrass.

Growth and yield parameter of rice

Number of tiller m^{-2}

Data analysis indicated that by increasing weed density from 0 to 25 plants for every m^2 the number of tillers m^{-2} of rice was diminished (Table 3). However, the number of tillers m^{-2} showed a cubic trend in 2018 and 2019 in response to weed density escalation. The highest number of tillers m^{-2} of rice (475 and 477 m^{-2}) in 2018 and 2019 were present in the weed-free control. However, the minimum number of tillers m^{-2} (162 in 2018 while 189 in 2019) was counted in the plots infested with 25 *L. chinensis* plants m^{-2}.

Table 3
Effect of different densities of *L. chinensis* on growth and yield components of direct seeded rice

Density (Plants m^{-2})	Number of tiller m^{-2}		Number of grains $panicle^{-1}$		1000-grain weight (g)	
	2018	2019	2018	2019	2018	2019
0	475 a	477 a	89.8 a	96.3 a	21.1 a	21.6 a
5	278 b	331 b	74.4 b	81.6 b	20.0 b	20.0 b
10	234 c	296 c	65.9 c	73.1 c	18.6 c	19.3 c
15	202 d	216 d	58.7 d	62.7 d	18.0 c	18.3 d
20	192 d	206 e	56.6 e	50.9 e	17.2 d	17.6 e
25	162 e	189 f	42.1 f	38.5 f	16.3 e	15.3 f
LSD	17.70	6.24	0.98	1.53	0.76	0.41
Trend comparison						
Linear	**	**	**	**	**	**
Quadratic	**	**	**	NS	NS	NS
Cubic	**	**	**	NS	NS	NS

Mean values followed same letter did not differ significantly at 5% probability level, ** significant at 1% probability level, * significant at 5% probability level, NS= non-significant.

Poor crop growth owing to *L. chinensis* interference had a significant injurious effect on the reproductive development of rice by diminishing the number of panicle m^{-2} and the 1000-grain weight, which were translated into grain yield loss. In our study, the number of tillers m^{-2} of rice was reduced from 65.8 to 60.3% with the increase in weed density. Additionally, Sultana (2000) documented a 52% reduction in the number of tillers m^{-2} due to weed crop competition. Similar findings were also reported by Al-Mamun, Shultana, Bhuiyan, Mridha, and Mazid (2011) who revealed that an increase in weed density significantly reduced the number of tillers, with the highest number of tillers being reported in weed-free conditions (Begum, Juraimi, Amartalingum, Omar, & Man, 2009; M. F. Islam, Karim, Haque, & Islam, 2003). Our results are also in compliance with Al Mamun et al. (2013) who also documented that the maximum number of tillers of rice was found in weed-free plots, which declined linearly with the increase in weed density.

Number of grains $panicle^{-1}$ and thousand-grain weight (g)

The number of grains per panicle is an imperative constraint that considerably improves the ultimate yield of rice. The maximum number of grains per spike (89.8 and 96.3) in 2018 and 2019 were counted in the weed-free condition (Table 3). As the density of *L. chinensis* was increased, a significant decrease in the number of grains per spike of rice was noted. The minimum number of grains per spike (42.1 and 38.5) was recorded in the highest density of 25 weeds m^{-2} in both years. The cubic trend of comparison was significant in 2018 and a linear trend was observed in 2019 for the number of grains per panicle, with an escalation in weed density in direct-seeded rice. In our study, 60 and 53% reductions in grains panicle^{-1}, and 23% and 29% reductions in 1000-grain weight were observed from where the highest (25 weed plants m^{-2}) weed density was sustained in two consecutive years.

As *L. chinensis* density increased in direct-seeded rice, 1000-grain weight gradually decreased in a linear fashion. The highest 1000-grain weight of rice (21.1 and 21.6 g) was chronicled in the control conditions in 2018 and 2019, correspondingly (Table 3). In 2018, the smallest 1000-grain weight (16.3 g) was documented in 25 weeds m^{-2}, while in 2019 the minimum weight (15.3 g) was observed in treatment that had the highest (25) weeds m^{-2}. These results are also in close resemblance to that of (Begum et al., 2009) who reported that 250 weed plants m^{-2} resulted in a maximum 1000-grain weight as compared to 500-1000 plants m^{-2} of Fimbristylis miliacea. Also, Karim and Ferdous (2010) reported that E. crus-galli and E. indica significantly affected the 1000-grain weight of rice. Similar results were also reported by (Iqbal et al., 2008; M. Islam, Khan, & Rahman, 1980; Mubeen et al., 2014) who depicted that grain yield was expressively reduced by the increase in weed density that might be due to establishing a strong competition between weed and crop. The 1000-grain weight is a genetic character widely used in yield estimation and varietal selection in rice (Iqbal et al., 2008). Also, similar results were reported by (Al Mamun et al., 2013; Babu, 2012; Karim & Ferdous, 2010) who observed that grain number per panicle of direct-seeded rice was reduced by the increase in weed density per unit area.

Economic yield (kg ha^{-1}) and yield losses estimation

Paddy yield is the result of numerous yield components of the crop. The analyses showed that each density level hampered the yield of rice due to gradually increasing competition between weed and crop plants (Table 4). Maximum paddy yield was recorded (2554 and 2618 kg ha^{-1}) in control conditions in 2018 and 2019, respectively. Paddy yield gradually decreased by increasing density from 5 to 25 weeds m^{-2} in a quadratic trend for 2018, whilst a cubic trend was observed in 2019. However, the lowest yield (957 kg ha^{-1}) was observed in plots where 25 weeds m^{-2} were maintained in 2018, while 824 kg ha^{-1} was recorded in 2019 in the plots infested with 25 weed plants m^{-2}. The estimated weed-free yields of the paddy are presented in Figures 2 and 3 for 2018 and 2019, respectively.

Table 4
Effect of different densities of L. chinensis on biological yield, harvest index and paddy yield of direct seeded rice

Density (Plants m^{-2})	Biological yield (kg ha^{-1})		Harvest index (%)		Paddy yield (kg ha^{-1})	
	2018	2019	2018	2019	2018	2019
0	12503 a	13038 a	20.4 a	20.0 a	2554 a	2618 a
5	10463 b	11181 b	19.5 b	19.2 b	2048 b	2157 b
10	9241 c	9279 c	18.8 c	18.5 c	1740 c	1724 c
15	7451 d	7892 d	17.7 d	17.2 d	1323 d	1351 d
20	7264 e	5991 e	16.4 e	16.5 e	1192 e	992 e
25	5878 f	5214 f	16.2 e	15.8 f	957 f	824 f
LSD	43.30	200.18	0.42	0.48	29.24	39.53
Trend comparison						
Linear	**	**	**	**	**	**
Quadratic	**	**	**	NS	NS	NS
Cubic	**	**	**	NS	NS	NS

Means value followed same letter did not differ significantly at 5% probability level, ** significant at 1% probability level, NS= non-significant.

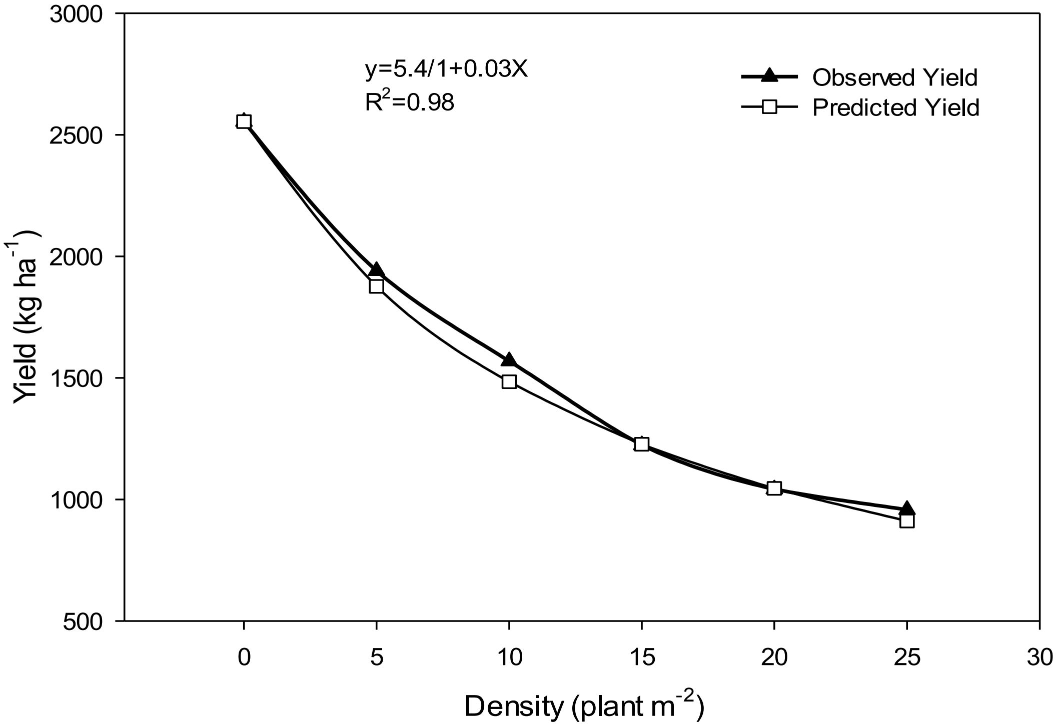

Figure 2. Non-linear regression line for rice yield for the year 2018 by (Cousens, 1985).

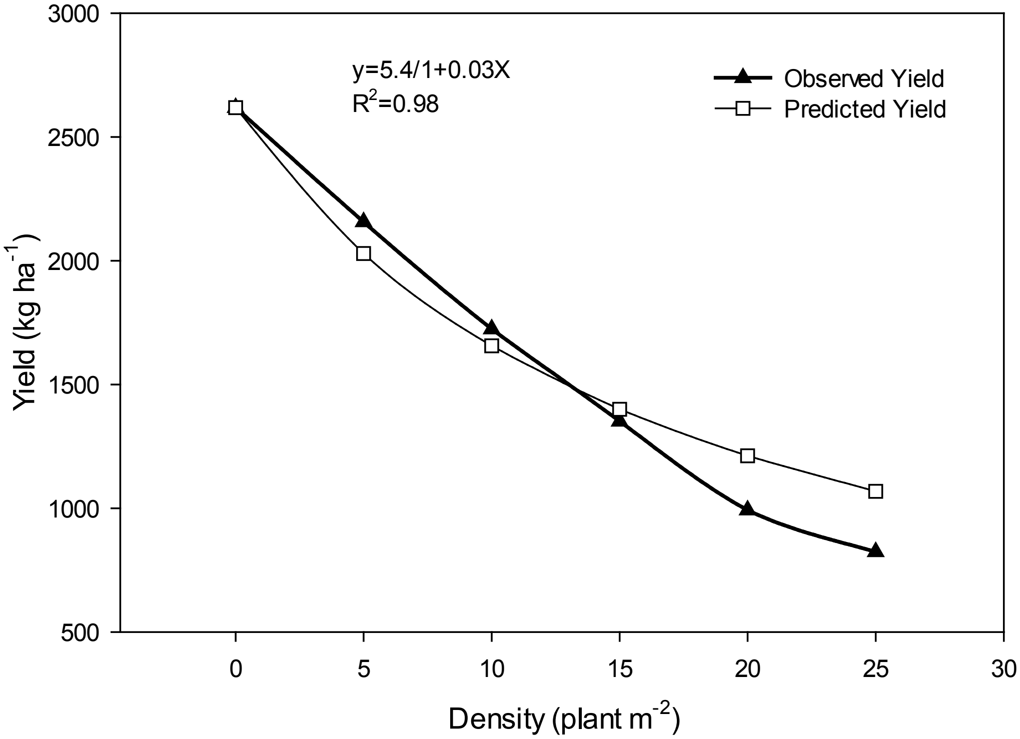

Figure 3. Non-linear regression line for rice yield for the year 2019 by (Cousens, 1985).

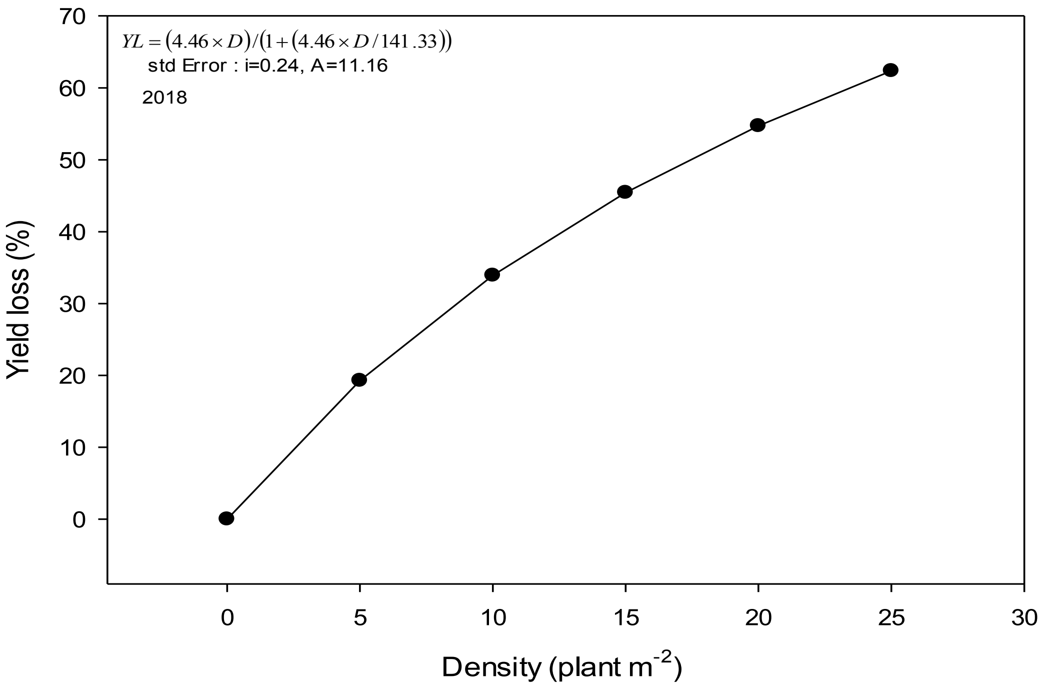

Figure 4. A rectangular nonlinear hyperbolic regression model estimate for direct-seeded grain yield loss (%). Abbreviations: *i*, percentage yield loss per unit weed density as D→ 0; *A*, percentage yield loss as d →∞.

The relationship between rice yield loss and *L. chinensis* density was described with a rectangular hyperbolic regression model. The results showed that parameter i, which described the yield loss per *L. chinensis* plant as density approaches zero was 4.46% in 2018 and 4.18% in 2019. However, the value of maximum yield loss of rice (*A*) was 141% and 214% (Figures 4 and 5). Reduction in paddy yield from 68.53 to 50.78% was recorded due to the reduction in yield-related parameters with the increase in each level of *L. chinensis* density, which also increased competition between the crop and the weed. With the increase in weed density, yield and yield-related components were decreased because of the competition experienced by rice at the higher weed density as the weeds decreased the accessibility of fundamental supplements for rice development. Alternating wet and dry conditions are conducive to the germination and growth of weeds that cause a reduction in grain yield (Fujisaka, Harrington, & Hobbs, 1994). Chauhan and Johnson (2011) also declared that high infestation of Echinochloa sp. throughout the growing season in direct-seeded rice reduced the final yield by about 95%. Likewise, Kankal, Mahadkar, Chendge, Burondakar, and Patil (2015) noticed a higher grain yield in DSR without weed control treatments. However, S. Kumar, Rana, and Chander (2013) reported that an increase of one weed m^{-2} up to harvest is expected to reduce the grain yield of rice by 15.3 kg ha^{-1} in direct-seeded rice. A decrease of 51-64% in yield of DSR was recorded when 100-200 plants m^{-2} of the weed were maintained (Sultana, 2000). Kwon, Moon, Kuk, Kim, and Kim (2006) also noticed a rice yield decrease of 11 to 74% and 1 to 12% because of 5 to 100 plants m^{-2} of E. crus-galli and M. vaginalis in the DSR, respectively. Abdullah Al Mamun (2014) calculated the ETL (economic threshold level) of multi-weed species as 4.72–9.17 plants m^{-2} which influenced yield deciding attributes of DSR like the number of panicles (m^{-2}), number of grains $panicle^{-1}$, and 1000-grain weight because of weed-crop competition.

Biological yield kg ha^{-1}

The biological yield of a crop is a total result of its dry matter accumulation which is produced due to net photosynthesis throughout its growth period. Biological yield is the overall biomass delivered by the grain yield from a unit area (Table 4). The biological yield was shown as a quadratic trend of comparison in both years of study in response to an increase in weed density in direct-seeded rice. The maximum biological yield was verified from control treatments in both years of study while minimum yield was recorded from the treatment having 25 weeds m^{-2}. Al Mamun et al. (2013) reported a noteworthy decline in crop growth rate due to an increase in weed populace.

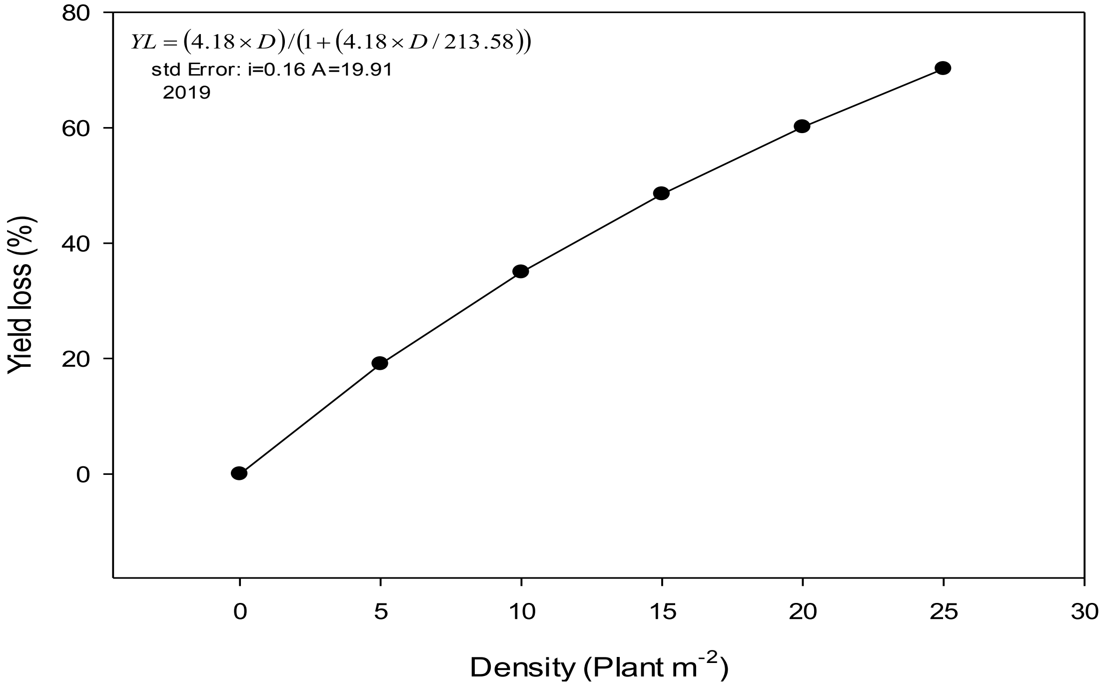

Figure 5. A rectangular nonlinear hyperbolic regression model estimate for dieect-seeded grain yield loss (%). Abbreviations: *i*, percentage yield loss per unit weed density as D→ 0; *A*, percentage yield loss as d →∞.

Harvest index (%)

Harvest index is the proportion of monetary yield and biological yield and it demonstrates the amount of assimilates move into the economic part of the plant. The physiological effectiveness and capacity of a harvest plant for changing over the total dry matter into financial yield is known as the harvest index. The higher the conversion of dry matter into a monetary element (grain), the higher the estimation of harvest index. Maximum harvest indices were produced in weed-free conditions (20.4 and 20.0) in 2018 and 2019, while it was gradually decreased by increasing weed density; this was shown as a linear trend of comparison (Table 4). (Mubeen et al. (2014)) documented the highest harvest index in a weed-free treatment in a weed density study.

Paddy yield losses and economic threshold of L. chinensis in direct-seeded rice

Keeping herbicide cost US$ 34.54 and 28.29, herbicide application cost US$ 8.22 and 7.19, value per unit of crop US$ 0.2344 and 0.1964, paddy yield losses per unit density 0.044 and 0.041 in 2018 and 2019, respectively, and herbicide efficiency for both years 0.95. Economic threshold level of *L. chinensis* was predictable 1.70 and 1.73 plant m^{-2} during the year 2018 and 2019 respectively (Table 5). Such a low ETL of *L. chinensis* weed in direct-seeded rice was shown that this weed is profoundly serious with crop plants. The estimation of the collected item is the main consideration to assess the ETL because of the higher monetary estimation of rice grain the ETL for *L. chinensis* weed was extremely low.

Table 5
Parameters for the estimation of economic threshold of L. chinensis in direct seeded rice

Weed	Year	Ch (US$)	Ca (US$)	Yo (Kg ha^{-1})	P (US$ Kg^{-1})	L	H	ET (plants m^{-2})
Leptochloa chinensis L.	2018	34.54	8.22	2554.5	0.2344	0.044	0.95	1.70
	2019	28.29	7.19	2618.8	0.1964	0.041	0.95	1.73

US$= United States Dollar, Ch = cost of herbicide, Ca = cost of herbicide application, Yo = paddy yield in weed free plots, P = value per unit of crop, H = herbicide efficacy, L = proportional loss per unit weed density, ET = economic threshold.

Conclusion

From the present study, it can be concluded that *L. chinensis* is a serious weed in the direct-seeded rice crop that caused up to 62.5% and 68.5% reduction in yield of rice in 2018 and 2019, respectively at its highest density 25 weed m^{-2}. Estimated economic threshold of *L. chinensis* weed was 1.70 and 1.73 plants m^{-2} causing 6.73% and 6.08% yield losses (2018 and 2019, respectively). It must be controlled at and beyond this density to avoid significant losses in grain yield.

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