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Crop Establishment Methods and Weed Management Practices Affect Grain Yield and Weed Dynamics in Temperate Rice

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Abstract: Higher demand and cost of labor and water shortage have forced the farmers to look for an alternate method of cultivation in rice as a substitute to the existing conventional transplanting. Dry direct seeding and water seeding have emerged as better alternatives over transplanting method. These methods not only result in labor saving, but also result in significant water saving in rice. These are important adaptation strategies to the impending climate change. However, the direct seeding method is confronted with severe weed infestation and yield losses if weeds are not managed well. Against this backdrop, a field study was undertaken during *kharif* seasons of 2019 and 2020 to evaluate the effect of crop establishment methods and weed management practices on rice and its associated weed flora. The results demonstrated that grain yields obtained under water seeding (WS) were statistically at par with transplanting (CT), but significantly superior to dry direct seeding (DDSR). Yield attributes were significantly superior in WS as compared DDSR, but were at par with CT. Weed density followed the order of DDSR > WS > CT. With the advancement in age of the crop, sedges dominated in DDSR, whereas broad-leafweeds (BLW) dominated in WS and CT methods of establishment. All the herbicides reduced the weed density significantly as compared to weedy check. Penoxulam (PE) reduced the weed density and weed dry matter on an average by 91% and 92% at 30 DAS/DAT over weedy check, respectively. PE proved significantly superior in controlling all the sedges and grasses but was less effective against BLW. Maximum reduction in yield due to weeds was observed in weedy check (WC) (58%) and the lowest was observed in PE (3%). Application of PE @ 22.5 g ha^{-1} under the WS method of crop establishment resulted in highest average weed control efficiency and grain yield.

Keywords: rice; dry direct seeding; water seeding; transplanting; establishment methods; weed management practices; herbicides; weed indices; weed flora

1. Introduction

Rice is the major food crop for most of the population, particularly in Asian countries, where more than 90.0 percent of global rice is produced and consumed [1]. In Asia, India is the second major producer of rice after China, with the contribution of 21.5% to the world rice production. Rice cultivation methods have been changing from time to time in response to technological developments, water and labor availability, and increased cost of production and higher cropping intensity. In India, rice is mainly cultivated through conventional transplanting method, however, alternative to this, direct seeding has been practiced successfully in the past two decades with few manipulations, depending on the geographic and agro-climatic conditions. Since then, several sowing and crop establishment methods have evolved, such as water seeding, dry direct seeding and wet seeding using dry or pre-germinated seeds, and these have offered promise in water scarce and labor shortage scenarios [2,3]. In Punjab (India) alone, the area under direct seeded rice has crossed 0.60 m ha during 2021. Due to increasing labor and water shortage, the area under direct seeding is expected to further increase in coming years. However, in different forms of direct seeding, reduced yields have been witnessed due to severe weed competition. In DSR, 90% yield penalty has been witnessed on account of severe weed competition [4,5], as the crop in this establishment method lacks the early head start and suppression effect of flooding on weeds normally achieved in the transplanting method. In India, an economic loss of USD 11 billion has been found to be inflicted by weeds alone in 10 major crops, out of which the share of rice is 21.4% and 13.8% in direct seeded and transplanted rice, respectively [6]. There are reports of lower [7], equal [8], or even higher [9,10] grain yield in direct seeded rice as compared to transplanted methods. Different means are put in practice to control this weed menace, though manual and chemical weeding methods are common. However, manual weeding is a laborious and back breaking process. Chemical weed control, which involves application of different pre- and post-emergent broad-spectrum herbicides, has been advocated in rice. Over the years chemical weed control has gained importance in controlling weeds, owing to its advantage over other methods of weed control, like ease in application and quick and effective control. A large number of pre-emergence herbicides, such as pendimethalin, oxadiazon, oxadiargyl, pretilachlor, etc. [11] and post-emergence herbicides such as cyhalofop–butyl, bispyribac-sodium, penoxsulam, fenoxaprop, azimsulfuron, 2,4-D, metsulfuron-methyl, triafamone + ethoxysulfuron etc. [12] are recommended and used in direct seeded and transplanted rice in India. However, a limited time window for herbicide application to suit varied crop environment is crucial for suppression of weeds in that particular scenario [13]. In this backdrop, a field experiment at Mountain Research Centre for Field Crops, SKUAST-Kashmir, was conducted to evaluate the response of rice and its associated weed flora to crop establishment methods and chemical weed management practices under temperate conditions.

2. Materials and Methods

2.1. Site Description

The field experiment was conducted during two consecutive *kharif* (May to September) seasons of 2019 and 2020 at Mountain Agricultural Centre for Field Crops Khudwani, Sher-e- Kashmir University of Agricultural Sciences and Technology of Kashmir (SKUAST-K). Previously the field was under rice for decades, established through the transplanting method. Herbicide butachlor, followed by one hand weeding, was the general practice of weed management. The site is located at 33.7237°N and 75.0916°E and an altitude of 1590 m. The region experiences a cold temperate climate with sub-zero temperatures during winter and warm weather during summer. This region has a short growing season of 140–150 days for rice crop. Soil samples were collected from upper 20 cm depth for assessing initial nutrient status. Laboratory analysis revealed that the soil of the experimental site is silty clay loam in texture, neutral in pH, low available N (210 kg ha^{-1}) and P (11.5 kg ha^{-1}), and medium in available K (225 kg ha^{-1}).

2.2. Experimental Design

The experiment was laid out in a split plot design with three replications. The treatments comprised of three crop establishment methods in the main plot and five weed management practices in subplots. The main plot treatments included dry direct seeding (DDSR), water seeding (WS), and transplanting (CT), and sub-plots included pyrozulsufuron + pretilachlor (PP) used as pre- emergence herbicide applied @ 60 + 45 g ha^{-1} at 3 DAS/DAT, penoxsulam (PE) a broad spectrum herbicide used as early post-emergence herbicide at 22.5 g ha^{-1} at 7 DAS/DAT, and bispyribac sodium (BS) applied as post-emergence herbicide at 25 g ha^{-1} at15 DAS/DAT. PP is the mixture of pyrazosulfuronethyl plus pretilachlor effective against grasses, sedges, and broad-leaf weeds, and is recommended for both transplanted and direct seeded rice. PE is effective against aquatic weeds recommended across rice establishment methods. BS controls a range of grass and broad-leaf weeds, and is the most widely used post-emergence herbicide in DSR systems in many countries [14]. A buffer zone of 1 m and 0.5 m was maintained between the main plot and subplot treatments to eliminate any cross effect of varied water levels and herbicide treatments. Weed free treatment was maintained by repeated manual weedings and weedy check did not receive any herbicide or manual weeding.

2.3. Crop Management Practices

The field received one primary tillage using a disc plough, followed by two tillings to get a fine tilth. A recently released high yielding rice variety, Shalimar rice-4, with a yield potential of 9 t ha^{-1} and maturity period of 140 days was used as the test variety. For DDSR, dry seed was put into the furrows at a depth of 2 cm and covered with the soil and irrigated immediately to stimulate the germination. Water seeded plots were prepared by puddling the soil using a power tiller and the pre-germinated seed was sown using a drum seeder. Each sub-plot was of 5 m × 4 m dimensions. The seed was sown @ 50 kg ha^{-1} at a row spacing of 20 cm × 10 cm in all the treatments. Pre-germinated seeds for the transplanting treatment were also sown on the same date in the nursery. The seedlings were transplanted at an age of 30 days and at a spacing of 20 cm × 10 cm. Afterwards, irrigation water was applied 2 days after disappearance of ponded water in DDSR and the recommended irrigation practices of standing 3–5 cm of water was maintained in WS and CT baring three drainage periods at recommended time periods. The nutrients were applied @ 120:90:60, N: P_2O_5: K_2O kg ha^{-1}. One third of nitrogen, full dose of phosphorus and potassium in the form of urea, DAP, and MOP were applied as basal, and remaining nitrogen was divided into two equal halves at 20 and 40 DAS/DAT.

2.4. Biometric Observations

Tillers were counted at two random spots within the net plot at 50 cm row length and the figures were then converted into tillers m^{-2}. Ten randomly tagged plants were selected and averaged for recording panicle length and grains per panicle. These sample panicles were hand threshed and averaged to record the number of grains per panicle^{-1}. Grain and straw yield were recorded from net plot in kg and converted into t ha^{-1}. 1000 seed weight was recorded from the produce obtained from net plot.

2.5. Weed Measurements

Weed density and dry matter were recorded at 30 and 60 DAS/DAT, both dates falling within the critical period of crop weed competition in rice. Quadrants were placed randomly in the sub-plots. Within these quadrants, the weeds were cut at the ground level and washed under tap water to remove the adhered soil. Then the weeds were counted and categorized in three categories viz. broad-leaf weeds (BLW), sedges, and grasses. The samples were air dried and finally oven dried at 70 °C and 10% RH untilconstant weight was achieved.

Weed control efficiency (WCE), weed index (WI), and weed persistence index (WPI) were calculated at 30 and 60 DAS/DAT using the following formulae.

$$\text{WCE} = \left(\frac{\text{x} - \text{y}}{\text{x}}\right) \times 100$$

where, x = Weed dry weight in weedy check
y = Weed dry weight in treated plot.

$$\text{WI} = \left(\frac{\text{a} - \text{b}}{\text{a}}\right) \times 100$$

where, a= yield from weed free plot
b = yield from treatment under consideration.

$$\text{WPI} = \frac{\text{Weed dry weight in treated plot}}{\text{Weed dry weight in control plot}} \times \frac{\text{Weed density in control plot}}{\text{Weed density in treated plot}}$$

All the yield attributes and yield parameters were computed as per the standard procedures.

2.6. Statistical Analyses

The data were subjected to statistical analysis using analysis of variance (SAS Software packages, SAS EG v4.3, SAS Institute Carry, North Carolina, US) and means of treatments were compared based on the critical difference (C.D) test at $p \leq 0.05$. The data on weed population and weed dry matter were subjected to square root transformation and the transformed values were used in analysis. Correlation of weed dry weight, panicle numbers m^{-2}, number of grains per panicle, and grain yield determined using SAS EG v4.3. The difference between the yield and yield attributes between the two years of study was statistically non-significant, and therefore the data were pooled.

3. Results

3.1. Weed Flora, Weed Density, and Weed Drymatter

Weed floristic composition of the experimental plots was diverse and comprised of all the three major groups viz. BLW, sedges, and grasses. The predominant weed species observed were *Echinocloa colonum*, *E. crusgali*, *Setaria gluaca*, *Digitaria sanguinalis*, *Ammnania baccifera*, *Rorripa amphibia*, *Potamogeton distinctus*, *Aechynomene indica*, *Polygonum hydropiper*, *Cyprus rotundus*, *C. irria*, *C. difformis*, *Fimbristylis millicea*, and *Scripus juncoides.* Composition of weed flora varied significantly across the establishment methods. During both the years, dry seeding and water seeding recorded a higher number of BLW and sedges. However, in the transplanted method, grasses dominated over sedges and BLW at 30 DAS/DAT (Figure 1a,b). With the advancement in number of days from sowing, weed flora also changed. At 60 DAS, weed flora in DDSR was different from water seeding and the transplanted method. In DDSR, sedges dominated over BLW and grasses at 60 DAS. In water seeding and transplanting method, BLW dominated the weed flora during both years (Figure 1c,d). Among herbicide treatments, PP and BS applied plots were found to be dominated by sedges, however PE treated plots were dominated by BLW at 30 DAS during both the years. PE proved superior in controlling sedges and grasses but was less effective against BLW. On the contrary, PP and BS controlled grasses and sedges but were less effective against BLW during both years at 30 DAS (Figure 2a,b). In PP treated plots at 60 DAS/DAT, BLW dominated sedges and grasses which indicate a decreasing effect of herbicides on BLW at latter stages of growth. PE appeared relatively more efficient as all the three species were reduced, though it was more effective against sedges and grasses (Figure 2c,d). Rice establishment methods and weed management practices significantly influenced weed density. Irrespective of establishment methods, the number of weeds increased from 30 to 60 DAS/DAT (Table 1). Among the establishment methods, weed density followed the order of DDSR > WS > CT. Weeds density in water seeding (WS) and transplanting (CT) methods remained at par with one another, yet differed significantly from DDSR during both years of experimentation at 30 and 60 DAS/DAT. Among weed management practices, all the herbicides reduced the weed density significantly compared to weedy check ranging from 69% and 80% in PP, 90% and 91% in PE, and 83% and 84% in BS at 30 DAS/DAT and 60 DAS/DAT, averaged over two years, respectively.

Table 1. Effect of crop establishment methods and weed management practices on weed density and weed dry matter.

Weed Management Practices	Establishment Methods Weed Density m^{-2}							
	30 DAS/DAT				60 DAS/DAT			
	DDSR	WS	CT	Mean	DDSR	WS	CT	Mean
PP	11.09 (127.0) *	7.42 (56.7)	5.05 (28.2)	7.86	11.25 (136.0)	7.50 (73.5)	6.98 (55.2)	8.58
PE	4.50 (19.75)	2.91 (8.5)	2.73 (11.1)	3.38	8.68 (89.9)	5.37 (28.8)	3.30 (11.0)	5.78
BS	7.19 (52.8)	4.74 (22.1)	5.64 (31.6)	5.86	7.84 (77.2)	8.86 (94.7)	6.95 (52.0)	7.88
WF	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71
WC	20.73 (432.2)	11.77 (140.8)	10.25 (105.8)	14.25	29.85 (900.0)	13.72 (195.5)	11.04 (123.9)	18.20
Mean	9.52	5.51	4.88		11.66	7.23	5.80	
CD ($p \leq 0.05$)	EM:0.32	WM:0.41	EM × WM:0.71		EM: 0.56	WM:0.72	EM × WM:1.24	
	Weed Dry Matter(g m^{-2})							
	30 DAS/DAT				60 DAS/DAT			
	DDSR	WS	CT	Mean	DDSR	WS	CT	Mean
PP	5.94 (36.48)	2.85 (10.57)	2.41 (8.41)	3.73	4.37 (20.13)	3.40 (12.81)	2.90 (9.27)	3.56
PE	3.04 (10.75)	2.20 (4.55)	1.78 (3.30)	2.34	2.91 (10.33)	2.10 (4.65)	2.52 (6.85)	2.51
BS	3.41 (13.72)	2.93 (9.32)	2.68 (8.20)	3.01	3.53 (14.28)	3.90 (16.46)	3.92 (20.18)	3.78
WF	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71
WC	11.77 (138.14)	8.72 (75.95)	7.40 (54.90)	8.69	8.58 (73.44)	6.60 (43.17)	5.89 (34.45)	7.02
Mean	4.61	3.48	3.00		4.02	3.34	3.19	
C.D ($p \leq 0.05$)	EM: 0.53	WM:0.68	EM ×WM:1.19		EM: 0.60	WM:0.77	EM × WM:NS	

* Figures in parenthesis are the original values. DDSR = Dry direct seeding, WS = Water seeding; CT= Conventional transplanting; EM = Establishment methods; WM= Weed management; PP = Pyrozosulfuron ethyl + pretilachlor; PE = Penoxulam; BS = Bispyribac sodium; WF= Weed free; WC=Weedy check; DOS= Days after sowing; DAT= Days after transplanting.

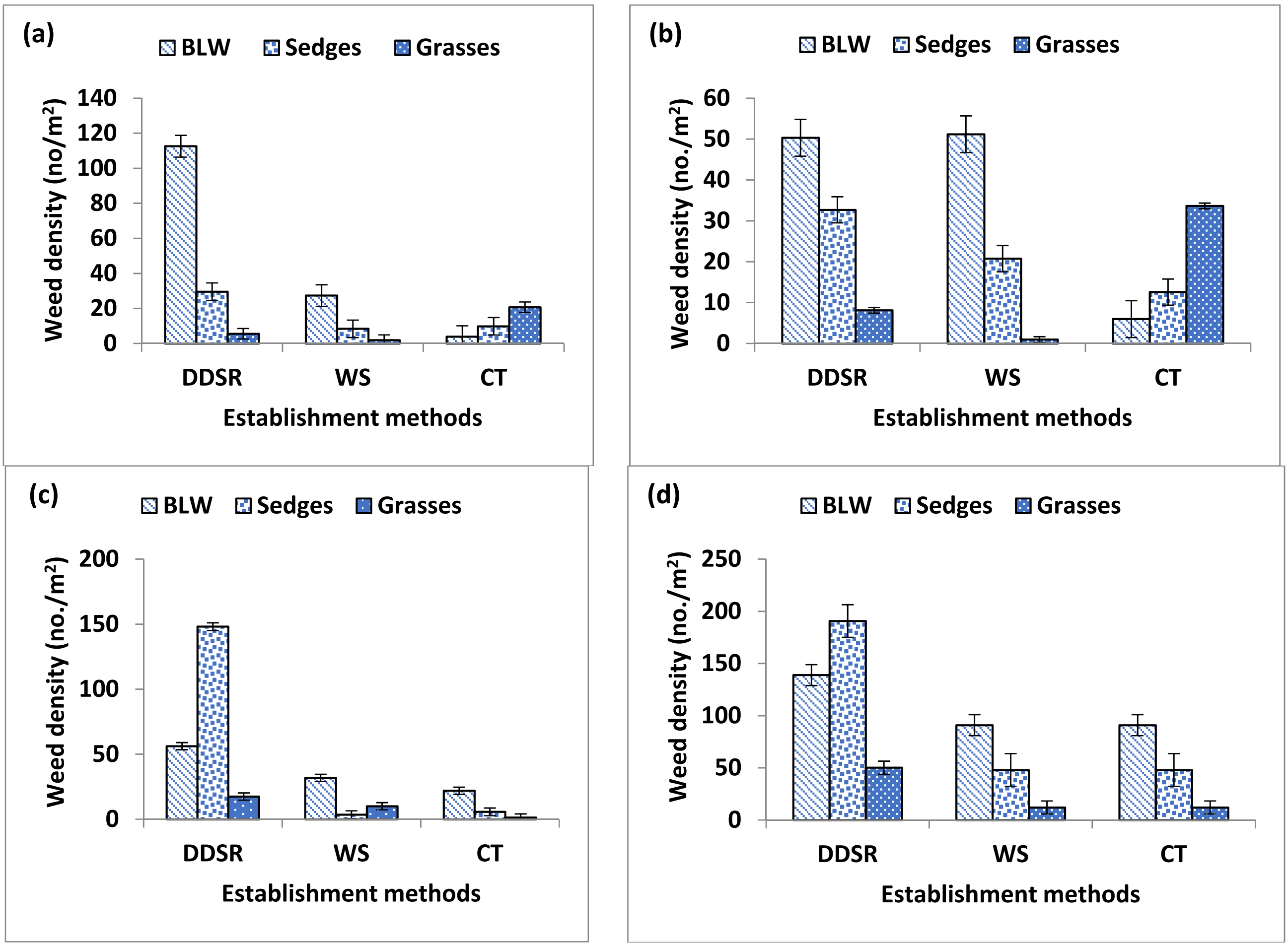

Figure 1. Effect of crop establishment methods on weed density (no. m^{-2}) as affected by crop 30 DAS 2019 (**a**), 30 DAS 2020 (**b**), 60 DAS 2019 (**c**), 60 DAS 2020 (**d**). Bars in the figures represent standard error of mean (SEM). DDSR—Dry direct seeding; WS—Water seeding; CT—Conventional transplanting; BLW—Broad-leaf weeds.

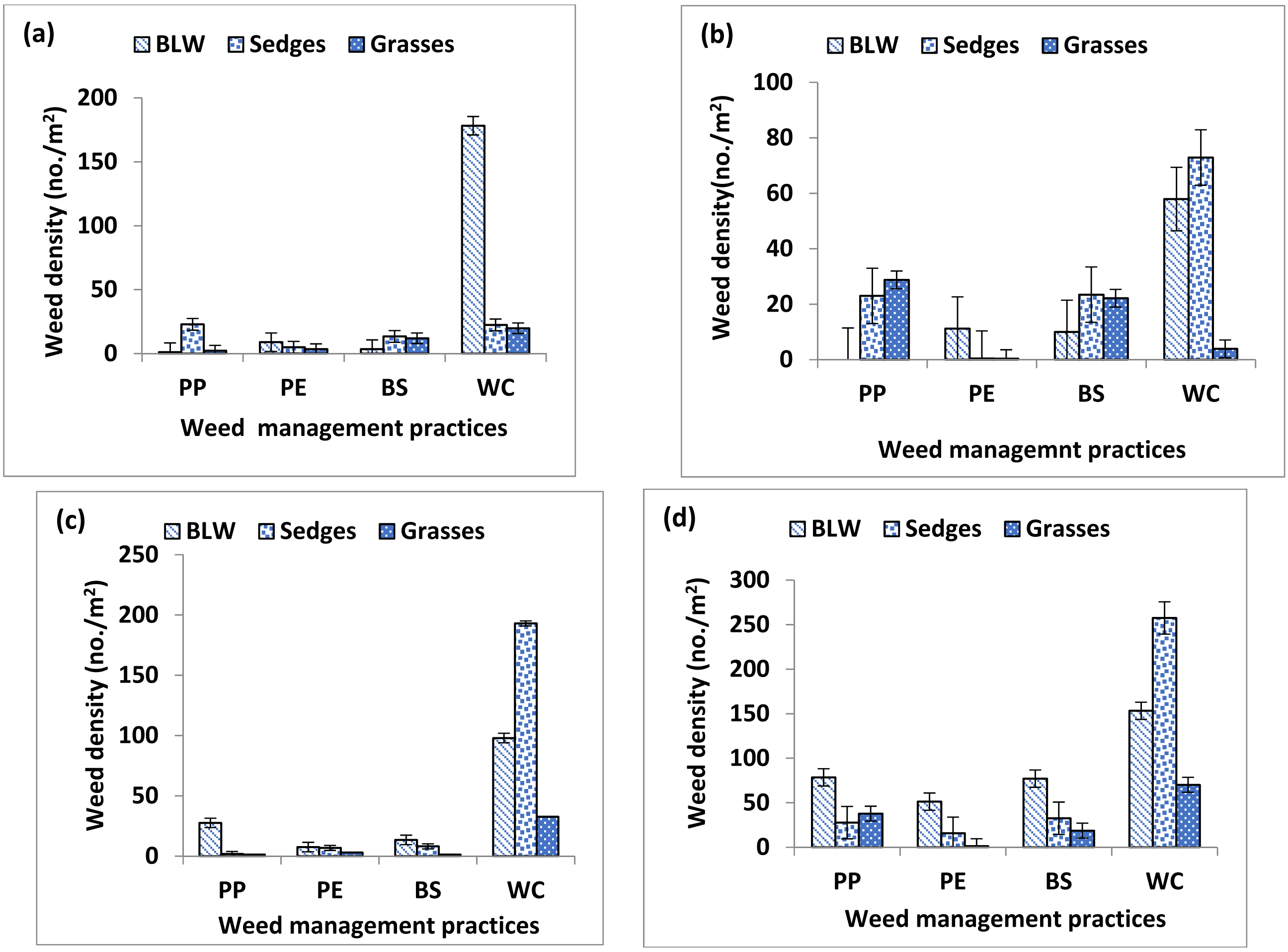

Figure 2. Effect of weed management practices on weed density no/m^2 30 DAS 2019 (**a**), 30 DAS 2020 (**b**), 60 DAS 2019 (**c**), 60 DAS 2020 (**d**). Bars in the figures represent standard error of mean (SEM); BLW—Broad-leaf weeds; PP—pyrozosulfuron ethyl + pretilachlor; PE—Penoxulam; BS—Bispyribac sodium; WF—Weed free; WC—Weedy check; DOS—Days after sowing; DAT—Days after transplanting.

Weed dry matter followed a similar trend to that of weed density (Table 1). However, weed dry matter was found to be less at 60 DAS compared to 30 DAS, irrespective of establishment methods. At 30 and 60 DAS, significantly higher weed dry matter was recorded with DDSR. Irrespective of the stage and years, the water seeding and transplanting method registered a 62% and 57% decrease in weed dry matter against DDSR method. Among the weed management practices, weed dry matter was in the order of PP > BS > PE, which amounted to a decrease of 72% to 86% to 93% to 71% and 67% to 88% at 30 DAS/DAT and 60 DAS/DAT over weedy check, respectively.

3.2. *Weed Control Efficiency, Weed Persistence Index, and Weed Index*

Among weed control treatments, the highest weed control efficiency (averaged over two years) was registered with PE, followed by BS and PP (Table 2). Early post-emergence application of PE showed the maximum weed control efficiency of 85% to 93%, followed by BS from 61% to 86% and PP 72% to 79% at 30 and 60 DAS/DAT over weedy check, respectively.

Mean weed persistence index values reflected variability among the crop establishment methods and herbicides.(Table 3). PE and PP recorded WPI of 0.70 and 0.79 at 30 DAS/DAT and 1.06 and 1.46 at 60DAS/DAT, respectively. However, the corresponding WPI values for BS were 0.79 and 1.48 (2.67) at 60 DAS/DAT.

Table 2. Effect of crop establishment methods and weed management practices on weed control efficiency (WCE) and weed persistence index (WPI).

Weed Management Practices	Establishment Methods							
	Weed Control Efficiency (WCE)							
	30DAS/DAT				60 DAS/DAT			
	DDSR	**WS**	**CT**	**Mean**	**DDSR**	**WS**	**CT**	**Mean**
PP	65.19	86.09	84.68	78.65	72.59	70.32	73.10	72.00
PE	89.74	94.01	93.99	92.58	85.93	89.24	80.13	85.10
BS	86.91	87.73	85.06	86.57	80.56	61.87	41.43	61.29
WF	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
WC	-	-	-	-	-	-	-	-
Mean	85.46	91.96	90.93		84.77	80.36	73.67	
Weed Persistence Index (WPI)								
	30DAS/DAT				60 DAS/DAT			
	DDSR	WS	CT	Mean	DDSR	WS	CT	Mean
PP	1.18	0.35	0.58	0.70	1.81	0.79	0.60	1.07
PE	0.71	0.99	0.57	0.76	1.41	0.73	2.24	1.46
BS	1.07	0.78	0.50	0.79	2.27	0.79	1.39	1.48
WF	-	-	-	-	-	-	-	-
WC	-	-	-	-	-	-	-	-
Mean	0.99	0.71	0.55		1.83	0.77	1.41	

DDSR—Dry direct seeding; WS—Water seeding; CT—Conventional transplanting; EM—Establishment methods; PP—Pyrozosulfuron ethyl + pretilachlor; PE—Penoxulam; BS—Bispyribac sodium; WF—Weed free; WC—Weedy check; DOS—Days after sowing; DAT—Days after transplanting.

Table 3. Effect of crop establishment methods and weed management practices on weed index.

Weed Management Practices	Establishment Methods			
	Weed Index (WI)			
	DDSR	**WS**	**CT**	**Mean**
PP	19.81	15.58	3.65	13.02
PE	4.92	2.48	1.39	2.93
BS	7.51	18.89	4.32	10.24
WF	-	-	-	-
WC	55.46	26.27	26.16	35.97
Mean	21.93	15.81	8.88	

DDSR—Dry direct seeding; WS—Water seeding; CT—Conventional transplanting; PP—Pyrozosulfuron ethyl + pretilachlor; PE—Penoxulam; BS—Bispyribac sodium; WF—Weed free; WC—Weedy check; DOS—Days after sowing; DAT—Days after transplanting.

Among the different weed control treatments, WI averaged over two years (Table 3) varied in the following order: WC > PP > BS > PE. Average reduction in grain yield for PP, PE, BS, and WF was 13%, 3%, 10%, and 36% over weedy check, respectively. Thefore, lowest WI was recorded for PE.

3.3. Yield Attributes

Yield attributes (mean of two years) viz. effective tillers m^{-2}, panicle length, 1000 grain weight, and number of grains panicle^{-1} were affected significantly by both establishment methods and weed control practices. The highest number of effective tillers m^{-2} were recorded in water seeding (WS), which was statistically at par with transplanting (CT) and the lowest in DDSR. Panicle length varied significantly higher in water seeding (WS) over DDSR but remained at par with the transplanting method (CT) (Table 4). A similar trend was reflected by 1000 grain wt. and number of grains panicle^{-1}. Among the weed management practices, the maximum number of effective tillers (323) was recorded in weed free plots. Among the herbicide treatments, PE recorded the highest number of effective tillers (306), followed by BS, PP with a significant reduction of 15.6%, 18.6% over WF. Weedy check recorded a maximum reduction of 60.6% over WF. Panicle length was significantly influenced by weed control treatments. PE proved to be as effective as weed free and produced its longest panicle of 25 cm. However, in the case of 1000 grain weight a reverse trend was registered, with the highest values in weedy check (29.7 g) which was statistically at par with PE (29.1 g), and the lowest was observed with PP (27.6 g). Although the maximum number of grains panicle^{-1} was recorded with weed free treatment (133), the same was at par with PE (132) and the lowest number was recorded with WC with 33% reduction over weed free treatment.

Table 4. Effect of crop establishment methods and weed management practices on yield attributes.

Weed Management Practices	Establishment Methods							
	Productive Tillersm^{-2}				**1000 Grain Weight (g)**			
	DDSR	**WS**	**CT**	**Mean**	**DDSR**	**WS**	**CT**	**Mean**
PP	199	280	295	258	26.96	28.03	27.88	27.62
PE	262	342	315	306	26.38	31.78	29.165	29.11
BS	229	272	294	265	28.63	26.86	27.83	27.77
WF	302	355	274	310	27.26	28.55	29.25	28.35
WC	159	201	256	206	31.03	28.93	29.21	29.72
Mean	230	290	287		28.05	28.83	28.667	
	EM:30.94	WM:26.09	EM × WM:NS		EM:0.44	WM:1.12	EM × WM:1.94	
	Panicle Length (cm)				**Grainspanicle^{-1}**			
	DDSR	WS	CT	Mean	DDSR	WS	CT	Mean
PP	22	24	24	23	97	119	127	114
PE	24	26	26	25	119	148	130	132
BS	23	23	23	23	114	115	115	114
WF	24	26	26	25	118	150	132	133
WC	22	23	23	23	94	103	105	100
Mean	23	24	24		108	127	121	
	EM:0.98	WM:1.15	EM × WM:NS		EM:4.63	WM:17.18	EM × WM:NS	

DDSR = Dry direct seeding; WS = Water seeding; CT = Conventional transplanting; EM = Establishment methods; WC = weed management; PP = Pyrozosulfuron ethyl + pretilachlor; PE = Penoxulam; BS = Bispyribac sodium; WF = Weed free; WC = Weedy check; DOS = Days after sowing; DAT = Days after transplanting.

3.4. Grain and Straw Yield

Grain yield was significantly influenced by both crop establishment methods and weed management practices (Table 5). Based on two years mean data, the highest grain yield of 7.40 t ha^{-1} was recorded in WS and the lowest was recorded in DDSR (6.04 t/ha). DDSR and CT resulted in 18.3% and 6.1% reduction in grain yield over WS, yet CT was at par with WS. Among the weed management practices, PE proved superior to others and registered a superiority of 11.7%, 8.78%, and 50.4% over PP, BS, and WC, respectively. Furthermore, severe reduction in the grain yield to the tone of 55% was recorded in weedy check against weed free. A significant interaction between crop establishment methods and weed management practices was recorded for crop yield (Table 3). PE proved superior to all other weed management practices and was at par with weed-free plots. PE and BS were equally effective under different crop establishment methods. However, PP was relatively inferior to the other two herbicides under DDSR.

Table 5. Effect of crop establishment methods and weed management practices on grain and straw yield.

Weed Management Practices	Establishment Methods							
	Grain Yield (t·ha^{-1})				Straw Yield (t·ha^{-1})			
	DDSR	WS	CT	Mean	DDSR	WS	CT	Mean
PP	5.87	7.12	7.26	6.75	10.16	11.00	9.72	10.29
PE	6.97	8.26	7.43	7.55	10.65	11.42	10.98	11.01
BS	6.77	6.87	7.21	6.95	10.37	10.74	9.33	10.15
WF	7.32	8.48	7.53	7.78	12.46	11.59	11.21	11.75
WC	3.26	6.25	5.26	4.92	8.06	10.06	8.05	8.72
Mean	6.04	7.39	6.94		10.34	10.96	9.86	
	EM:0.65	WM:0.55	EM × WM:0.95		EM:0.78	WM:0.89	EM × WM:1.62	

DDSR—Dry direct seeding; WS—Water seeding; CT—Conventional transplanting; EM—Establishment methods; WC—weed management;PP—Pyrozosulfuron ethyl + pretilachlor; PE—Penoxulam; BS—Bispyribac sodium; WF-Weed free; WC—Weedy check; DOS—Days after sowing; DAT- Days after transplanting.

3.5. Relationship of Grain Yield with Weed Density and Weed Dry Matter

Grain yield demonstrated a significant but negative correlation with weed density and weed dry matter. The coefficient of determination (R^2 $p \leq 0.05$) between the grain yield and weed density was 0.835 and 0.810 at 30 DAS/DAT during 2019 and 2020, respectively (Figure 3a,b). This means that 74.3% and 80.6% of the variation in the grain yield could be explained by weed density. Similar results were obtained from the regression analysis between grain yield and weed density. The R^2 at 60 DAS/DAT during 2019 and 2020 was 0.810 and 0.697, respectively (Figure 3c,d). The outcome of the regression analysis showed that with the increase of every ten number weeds m^{-2} there was 0.009 kg m^{-2}, 0.005 kg m^{-2} and 0.011 kg m^{-2}, 0.004 kg m^{-2} decrease in grain yield of rice during 2019 and 2020 at 30 DAS and 60 DAS, respectively. Regression analysis between grain yield also demonstrated a significant and negative correlation with weed dry matter. The coefficient of determination ($R^2 p \leq 0.05$) between the grain yield and weed dry matter was 0.789 and 0.766 at 30 DAS/DAT during 2019 and 2020, respectively (Figure 4a,b). This means that 76.0% and 76.9% of the variation in the grain yield could be explained by weed dry matter. The R^2 at 60 DAS/DAT during 2019 and 2020 was 0.824 and 0.779, respectively (Figure 4c,d). Regression analysis further reflected that an increase of every 50 g weed dry matter m^{-2} at 30 DAS reduced the grain yield by 0.031 kg m^{-2}, 0.051 kg m^{-2}, and at 60 DAS 0.028 kg m^{-2}, 0.059 kg m^{-2} during 2019 and 2020, respectively.

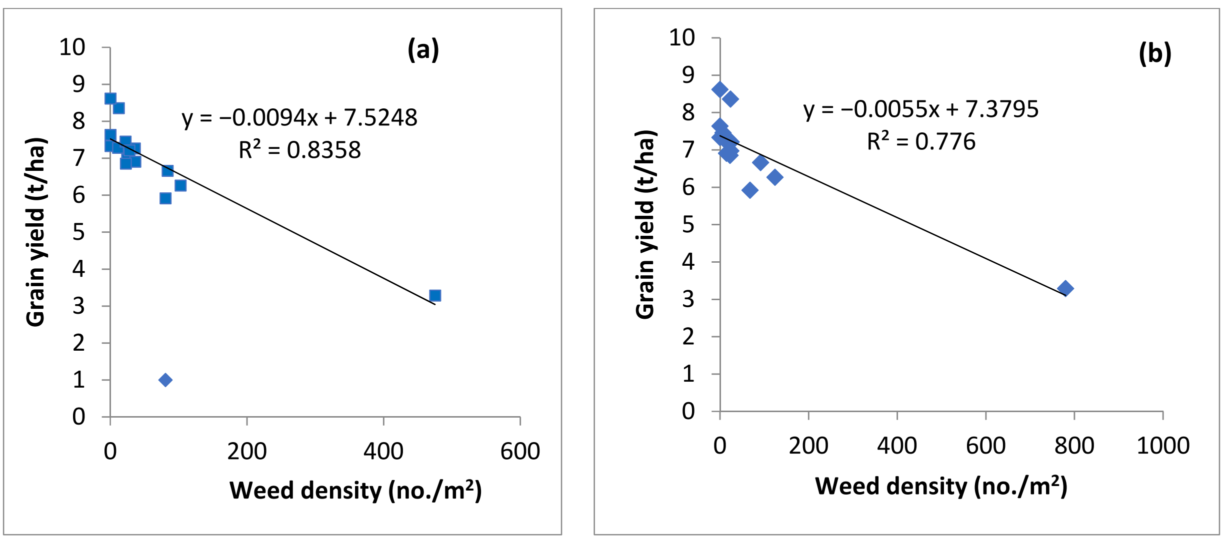

Figure 3. *Cont.*

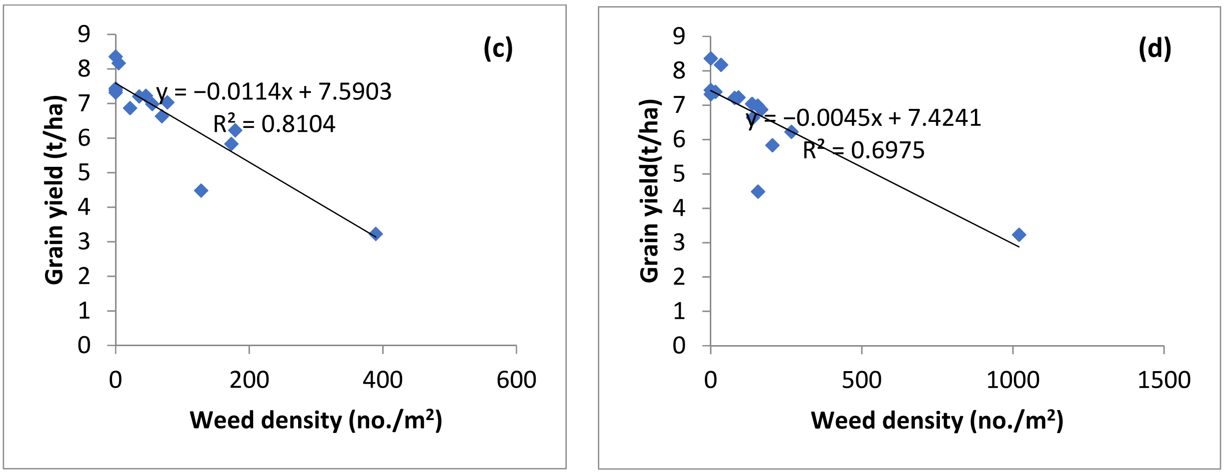

Figure 3. Relationship between grain yield and weed density/m^2 at 30 DAS/DAT (**a**) and 60 DAS/DAT (**b**) in 2019 and 30 DAS/DAT (**c**) 2020 at 60 DAS/DAT (**d**) in 2020.

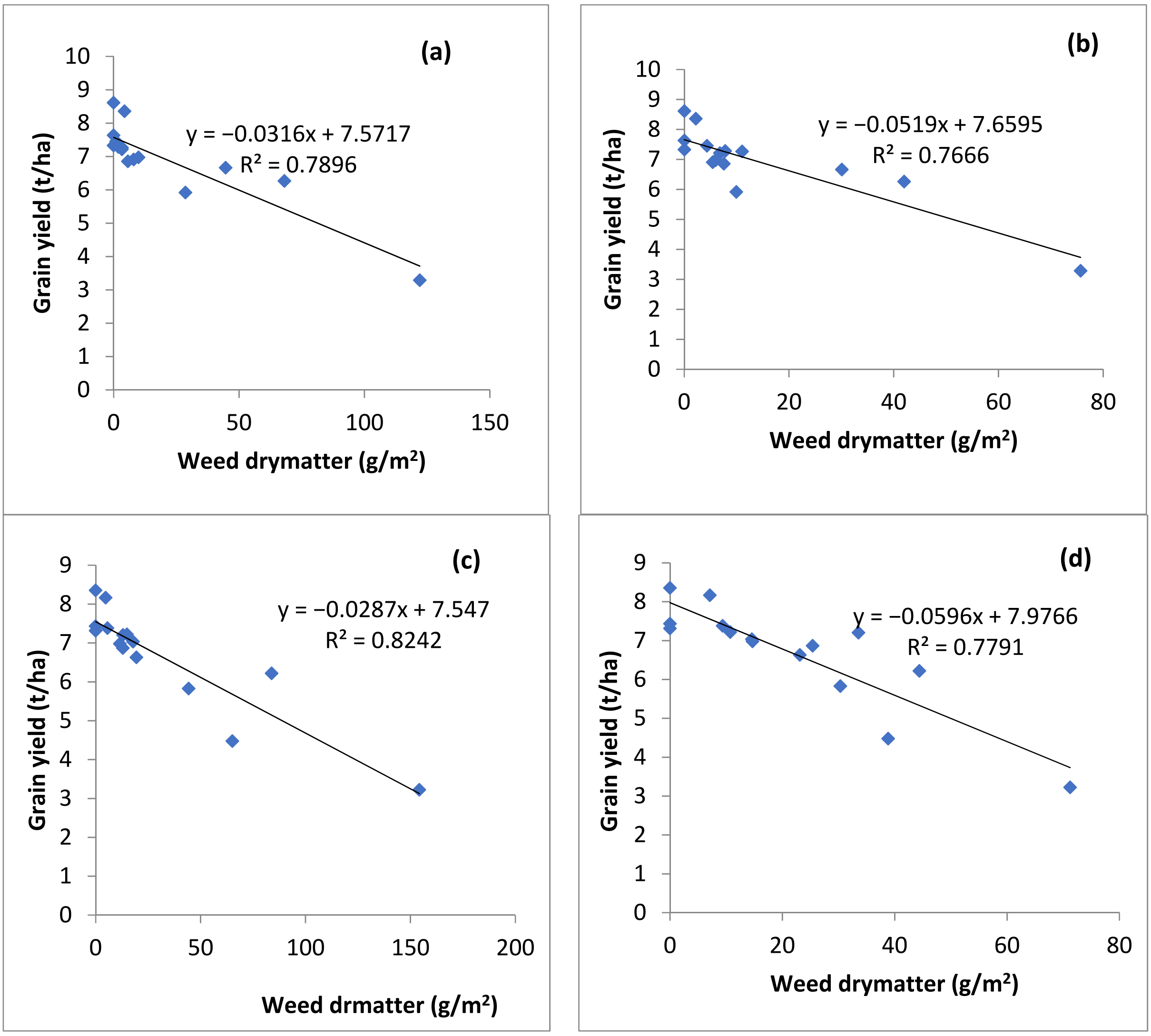

Figure 4. Relationship between grain yield and weed dry matter (gm^{-2})at 30 DAS/DAT (**a**) and 60 DAS/DAT (**b**) in 2019 and 30 DAS/DAT (**c**) 2020 at 60 DAS/DAT (**d**) in 2020.

4. Discussion

Our results indicated that weed floral composition varied with the establishment methods and stage of the crop. DDSR reported the maximum weed density, which significantly decreased in transplanting method. Higher weed density in DDSR can be attributed to a more aerobic soil environment that stimulates the germination of diverse weed species. Further size differential of rice seedlings in CT offers it a competitive advantage against the emerging weeds [15]. At early stages, weed flora was dominated by BLW and grasses in DDSR and in WS, BLW followed by sedges over grasses. In CT plots, grasses followed by sedges dominated the weed flora. The luxuriant growth of some BLW (*Potamogeton* sp., *Ammania* sp. *Marsilia quadrifolia* etc.) in flooded environments has widely been reported. This variation in weed groups among different establishment methods can be attributed to differences in land preparation methods, water retention, and soil physical conditions [15,16]. The shift in the weed flora in DDSR from BLW to sedges with the advancement in age of the crop could be attributed to environment suitable for sedges viz. low moisture as against BLWs, which dominated in flooded conditions. All the herbicides were able to control weeds significantly irrespective of weed groups, however, early post-emergence application of PE was found to be more effective against sedges and grasses at earlier stages, and with the advancement in number of days it was also able to control BLW [17].

The highest weed density and dry matter was recorded in DDSR. This increase in density and biomass can be attributed to congenial environment provided to the weeds in DDSR, in comparison to rice culture in WS and CT. In WS and CT, the advantage was in favor of crop, owing to better seed bed preparation and puddling of the soil in standing water. Puddling in WS and CT created conducive conditions for fast growth of crop at an earlier stage, resulting in smothering of weeds. Land preparation in standing water resulted in destruction of existing weed flora and the soft puddle promotes faster rice growth [18], suppressing the majority of weeds. Maximum density of weeds in DDSR is attributed to dry tillage, the absence of flooding resulting in the creation of more aerobic environments during crop establishment [19]. In a study on crop establishment methods and weed management practices in Banagladesh, significantly higher weed densities and weed biomass has been reported in conventional-till DSR than conventional transplanting across weed control methods [16]. These observations are also in conformity with the results of many workers [20]. Many researchers have reported lower weed density and dry matter in well puddled conditions followed by continuous submergence of water as compared to DSR and aerobic rice fields [14,15]. BS and PE resulted in higher reduction in weed density and weed dry matter. Early post-emergence herbicides have provided effective control against weeds in many studies [21].

In this study, variable weed control efficiency of herbicides was evident in different methods of establishment. One of the possible reasons for this variation among efficiency of herbicides could be time of application. Higher efficiency of PE can also be attributed to its time of application and its slow degradation in comparison to pre-emergence and post-emergence application of PP and BS, respectively. Pre-emergence application of PP provided a moderate control in DDSR. Relatively aerobic conditions exposed the herbicide to degradation as the crop took more time to establish and could not cover the soil, favoring successful emergence of subsequent flushes of weeds. BS being applied as post-emergence ensured its proper retention on the leaf surface of weeds, which might have led to its better absorption and efficiency and might have delayed the appearance of subsequent flushes, only to be smoothed by the crop by that time. However, the situation was different in other methods of establishment where it appears that early control of early flushes is more important. Since BS is more effective against grassy weeds and a few sedges, BLW dominated at 60 DAS/DAT [22].

Weed persistence index indicates relative dry matter accumulation of weeds per count in comparison to control. Weed persistence index, which demonstrates the resistance of escaped weed against the particular weed control measure, reflected variability. This variation in WPI values recorded with different weed control treatments at different stages

(30 and 60 DAS/DAT) can be attributed to variation in the window of efficiency of herbicides. However, at 30DAS/DAT, WPI of PE was found to better in DDSR and CT, which can be ascribed to its broad spectrum of weed control. Application of penoxulam [23] and pendimethalin, followed by penoxulam, recorded the lowest WPI [24].

Yield reduction owing to competition from weeds is represented by weed index. Among the herbicides, PE proved superior to other herbicides in reducing the weed density and weed dry matter. The reason could be broad spectrum nature of PE, which is effective against BLW, sedges, and grasses [13]. Penoxulam kills the weeds by inhibiting root growth while inhibiting acetolactase synthase enzyme (ALS). On account of the broad-spectrum nature of PE and significant reduction in weed density and weed dry matter, it resulted in lowest WI [23]. Our results are also in conformity with the findings of many researchers [25–27], who reported higher efficiency of PE as compared to BS and PP in direct seeded rice.

The highest grain yield obtained in WS can be attributed to better expression of yield attributes, particularly to a greater number of effective tillers which accounts for about 89% of the yield variation in rice [28]. There are reports of at par [14] or lower [7] yield in DSR as compared to transplanted rice. A similar yield in the weed control treatments can be attributed to better weed control efficiency. The significant differences between yield attributes ultimately were reflected in the grain yield. Among the herbicides, maximum grain yield was recorded with PE, which can be ascribed to its increased weed control efficiency and broad spectrum weed control [27]. The reduced efficiency of BS in WS and CT method can be attributed its minimal translocation [29]. Under DDSR, an extensive root system of the weeds might have led to its increased efficiency against PP. Similar results of reduced shoot and root biomass of rice plants under saturated condition as against under aerobic condition in BS applied plots was reported by many researchers [30]. Significantly negative correlation between weed density/weed dry matter and grain yield indicates competition of weeds for resources with crop up to 60 DAS/DAT. These results are further supported by the findings of many researchers [31], who observed 0–71 and 2–98 DAS as critical for weed competition in direct seeded rice under saturated and flooded conditions, respectively. Weed interference results in reduces crop biomass and its subsequent partitioning into the grains, and therefore demonstrates a negative correlation with weed density and weed dry matter. Such negative correlations have been widely reported in literature [32–34]. The study also specifies that information of weed density or weed dry matter at 30 to 60 DAS in rice will provide a valuable input for prediction of grain yield reduction in dynamic simulation models. Thus, estimated values of weed density or weed dry matter are valuable in puts for predicting rice production in the Kashmir valley, as affected by the presence of weeds.

5. Conclusions

From the two-year study, it was concluded that in DDSR and WS, BLW and sedges dominated over grasses at 30 DAS/DAT. The highest number of weeds and weed dry matter per unit area was recorded in DDSR across the chemical weed management practices. In weedy check, DDSR recorded the highest weed pressure in respect to weed density and weed dry matter per unit area. For realizing higher grain yield, WS and CT appear as better crop establishment methods over DDSR. However, among the herbicides, PP registered lowest WCE and grain yield in DDSR. Overall, the efficacy of PE was better in reducing weed density and weed dry matter across the crop establishment methods. Application of penoxulam @ 22.5 g ha^{-1} in WS recorded the highest WCE and grain yield.

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