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Studies on crop weed competition and weed management in direct seeded rice under puddled and unpuddled conditions

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Abstract
A field experiment was carried out in Central farm of Agricultural College and Research Institute, Madurai during *rabi* (*late samba*), 2018-19 to study the crop weed competition and weed management in direct seeded rice under puddled and unpuddled conditions. The experiment was laid out in strip plot design with twenty-eight treatmental combinations and three replications. The results revealed that among sowing methods, weed density was recorded higher in aerobic condition and among weed management practices weedy upto panicle initiation stage had recorded the highest weed density whereas weed free upto panicle initiation stage had recorded the lowest weed density, weed index and highest WCE and higher yield. With regard to chemical weed management, the combination of Bensulfuron methyl + Pretilachlor (10 kg a.i. ha^{-1}) *fb* 2,4-D (1.25 kg a.i. ha^{-1}) + one Hand weeding @ 45 DAS had recorded the lowest weed density with highest WCE as well as highest grain and straw yield. The next best treatment recorded was the application of Pendimethalin (2.5 kg a.i. ha^{-1}) + Bispyribac sodium (50 g a.i. ha^{-1}) *fb* one Hand weeding @ 45 DAS.

Keywords: 2,4-D, Bensulfuron methyl + Pretilachlor, Bispyribac sodium, Pendimethalin, weed density, weed control efficiency

Introduction
Rice (*Oryza sativa*. L) is the most important human food which feeds half of the world population. In India, rice occupies an area of 43.1 million hectares and its productivity is around 2.6 tones ha^{-1} (India stat, 2017-18). It is mostly grown under flooded condition in puddled soil which is highly cumbersome and laborious. The puddling deteriorates soil physical properties by breaking the capillary pores, destroys soil aggregates and ultimately results in formation of hard pan which affects the initial establishment and growth of succeeding crops. However, the direct seeded rice is considered as the best alternative for transplanting, heavy weed infestation is one of the major constraints for its adaptation. Direct seeding involves dry and wet seeding in which seeds are sown directly in the main field rather than transplanting. In dry direct seeding, it is sown by either broadcasting or dibbling and in wet seeding, pre germinated seeds are sown under puddled conditions (Kaur and Singh, 2017) [8]. In India, yearly loss of rice grain production is around 15 million tones due to heavy weed infestation (Singh *et al*., 2018) [10]. Weed management is considered as one of the difficult task in direct seeded rice due to simultaneous emergence of crop and weed. Weeds not only compete with the crop for space, light, water and nutrients but also hinders its quality. Weeds emerge at the initial crop growth stage are highly competitive than late emerging weeds. Hence the timely weed management is essential for direct seeded rice. However manual weeding is the traditional method, increased wages and demand for labour in non - agricultural sectors results in labour migration from rural to urban areas, it is difficult to find the labour at peak periods. Hence, chemical weed management by the combination of pre and post emergence herbicides is highly efficient and cost effective method. Keeping this in view, an attempt was made to study the crop weed competition and to find an ideal weed management method for direct seeded rice under puddled and unpuddled conditions.

Materials and methods
The field experiment was conducted in field No.48 of B block at Central farm, Agricultural College and Research Institute, Madurai during *rabi* (*late samba)*, 2018-19. The experimental

field soil is sandy clay loam in texture with soil pH and EC of 7.81and 0.32 dSm^{-1}, respectively. The short duration variety ASD 16 and the medium duration variety TKM 13 were used. The pre germinated seeds at the seed rate of 30-40 kg ha^{-1} with row spacing of 20 cm was sown by drum seeder under puddled condition and hand dibbled in aerobic condition. The experiment was laid out in strip plot design with twenty-eight treatmental combinations and replicated thrice. Main plot consists of four treatments *viz.* M_1 – Short duration rice under unpuddled condition (Aerobic), M_2 – Medium duration rice under unpuddled condition (Aerobic), M_3 – Short duration rice under puddled condition (Wet-seeded), M_4 – Medium duration rice under puddled condition (Wet-seeded) and sub plot consists of seven treatments such as S_1 – Weed free upto active tillering (AT) stage , S_2 – Weed free upto panicle initiation (PI) stage , S_3 – Weedy upto active tillering (AT) stage, S_4 – Weedy upto panicle initiation (PI) stage , S_5 – Pendimethalin (2.5 kg a.i. ha^{-1}) *fb* one Hand weeding @ 45 DAS, S_6 – Bensulfuron methyl + Pretilachlor (10 kg a.i. ha^{-1}) *fb* 2,4-D (1.25 kg a.i. ha^{-1}) + one Hand weeding @ 45 DAS , S_7 – Pendimethalin (2.5 kg a.i. ha^{-1}) + Bispyribac sodium (50 g a.i. ha^{-1}) *fb* one Hand weeding @ 45 DAS. The observations on weed density and weed control efficiency of grasses, sedges and broad leaved weeds were recorded at 15, 30, 45 and 60 DAS. The grain yield was recorded at 14 percent moisture and straw yield was recorded after sundried and both were expressed in kg ha^{-1}. Based on yield data, weed index was worked out. Data was statistically analysed as per Gomez and Gomez (1984). The data on weed density was subjected to square root transformation ($\sqrt{x} + 0.5$).

Results and discussion

Weed density (Nos. m^{-2})

The data on weed density of grasses, sedges and broad leaved weeds were given in table 1. Among sowing methods, at 15 & 30 DAS, the highest weed density of 49.21 & 101.71(grasses), 14.43 & 44.95 (sedges) and 68.10 & 80.57 (broadleaved weeds) m^{-2}, respectively were recorded in short duration rice variety under aerobic condition. This was found to be at par with medium duration rice variety under aerobic condition. Under puddled condition at 15 & 30 DAS, the varieties do not show any significant differences in weed density. At 45 & 60 DAS, medium duration rice variety under aerobic condition had recorded the highest weed density of 126.67 & 52.79 (grasses), 65.04 & 25.10 (sedges) and 100.56 & 40.63 (broadleaved weeds) m^{-2}, respectively. The results revealed that in aerobic condition broadleaved weeds had recorded the highest weed density followed by grasses and sedges at initial stage (15 DAS). Whereas at 30, 45 & 60 DAS, grassy weeds have recorded the highest weed density followed by broadleaved weeds and sedges. Lowest weed densities were observed in puddled condition during all the stages. This might be due to the disturbance of weed seed bank during puddling and ponding water in puddled field may limits the germination of weeds when compared to aerobic condition. This was in accordance with the findings of Nandan *et al*. (2018) [9].

Among the weed management practices, in 15 & 30 DAS, weed density was 0.0 (completely absent) in weed free upto active tillering stage and panicle initiation stage which might be due to maintenance of weed free condition by regular weeding. At 15 & 30 DAS highest weed density of 153.58 & 213.17 (grasses), 29.67 & 93.17 (sedges) and 120.83 & 159.58 (broadleaved weeds) m^{-2}, respectively were recorded in weedy upto active tillering stage. This was found to be at par with weedy upto panicle initiation stage of about 153.48 & 213.83 (grasses), 29.62 & 93.92 (sedges) and 121.45 & 161.25 (broadleaved weeds) m^{-2}, respectively. At 45 & 60 DAS, weedy upto panicle initiation stage had recorded the highest weed density of 238.92 & 144.17 (grasses), 123.25 & 76.58 (sedges) and 213.92 & 110.91 (broadleaved weeds) m^{-2}, respectively. Unweeded condition may favor increased weed density.

Regarding chemical weed management, at 15, 30 & 45 DAS application of Bensulfuron methyl + Pretilachlor (10 kg a.i. ha^{-1}) *fb* 2,4-D (1.25 kg a.i. ha^{-1}) + one hand weeding @ 45 DAS had recorded the lowest weed density of 5.60, 37.50 & 51.75 (grasses), 4.13, 31.33 & 42.75 (sedges) and 6.78, 1.91 & 4.17 (broadleaved weeds) m^{-2}, respectively. This might be due to that bensulfuron methyl comes under sulfonylurea group of herbicides which controls the complex weed flora at initial stages and pretilachlor will control the weeds by inhibiting the cell division and protein synthesis, whereas the post emergence application of 2,4- D was effective against broad leaved weeds and the weeds emerged at later stages were removed by hand weeding. However, at 45 DAS lowest weed density of sedges of about 35.12 m^{-2} was noticed in the treatment of Pendimethalin (2.5 kg a.i. ha^{-1}) + Bispyribac sodium (50 g a.i. ha^{-1}) *fb* one hand weeding @ 45 DAS. This might be due to the effect of bispyribac sodium on sedges which lowers its weed density of certain sedge weeds. Similar results were given by Bhullar *et al*. (2016) [3] and Chakraborti *et al*. (2017) [14].

Weed Control Efficiency (WCE) (%)

The data on WCE of grasses, sedges and broadleaved weeds were depicted in table 2. Among sowing methods, the weed control efficiency was non-significant in 15 and 30 DAS for grasses and sedges. With regard to broad leaved weeds, the weed control efficiency was non- significant in 15 DAS, whereas at 30 DAS the weed control efficiency of broadleaved weeds was registered high in short duration rice variety under puddled condition with weed control efficiency of 59.2 per cent. This was at par with medium duration rice variety under puddled condition with weed control efficiency of 59.2 per cent. At 45 & 60 DAS, short duration rice variety under puddled condition had recorded the highest weed control efficiency of 74.6 & 99.4 (grasses), 69.6 & 100 (sedges) and 74.9 & 99.2 (broad leaved weeds) per cent which was on par with short duration rice variety under aerobic condition with the weed control efficiency of 73.0 & 99.3 (grasses), 67.2 & 99.9 (sedges) and 72.4 & 99.0 (broad leaved weeds) per cent, respectively. Among broadleaved weeds, at 30 DAS the lowest weed control efficiency of 55.1 per cent was noticed in short duration rice variety under aerobic condition which was on par with medium duration rice variety under aerobic condition with the weed control efficiency of 55.3 per cent. Whereas at 45 & 60 DAS, medium duration rice variety under aerobic condition had registered the lowest weed control efficiency of 59.3 & 71.2 (grasses), 52.6 & 85.7 (sedges) and 72.4 & 99.0 (broadleaved weeds). This was on par with medium duration rice variety under puddled condition had recorded the lowest weed control efficiency of 60.5 & 71.3 (grasses), 55.2 & 85.7 (sedges) and 60.9 & 85.2 (broadleaved weeds). The results revealed that the varieties and sowing methods do not show any significant effect on weed control efficiency of grasses, sedges and broadleaved weeds at initial stage whereas at later stage, short duration rice variety under both puddled and aerobic condition had recorded the highest weed control efficiency. This might be

due to the reduced duration of short duration variety results in increased canopy cover which suppress the weed emergence than medium duration rice variety.

Regarding weed management practices, the weed control efficiency of grasses, sedges and broadleaved weeds were registered 100 per cent in the treatment of weed free upto panicle initiation stage during 15, 30 and 45 DAS. This was on par with weed free upto active tillering stage during 15 and 30 DAS. This might be due to the complete removal of weeds by periodic weeding. The next best treatment recorded was the application of Bensulfuron methyl + Pretilachlor (10 kg a.i. ha^{-1}) *fb* 2,4-D (1.25 kg a.i. ha^{-1}) + one hand weeding @ 45 DAS had recorded the highest weed control efficiency of 97.1, 86.4 and 80.1 per cent during 15, 30 and 45 DAS, respectively which was on par with application of Pendimethalin (2.5 kg a.i. ha^{-1}) + Bispyribac sodium (50 g a.i. ha^{-1}) *fb* one hand weeding @ 45 DAS with weed control efficiency of 95.4 per cent and in the application of Pendimethalin (2.5 kg a.i. ha^{-1}) *fb* one hand weeding @ 45 DAS with weed control efficiency of 95.5 per cent for grasses at 15 DAS. However, for sedges at 15 and 30 DAS, the weed control efficiency of 84.1 and 67.4 per cent was noticed high in the treatment of Bensulfuron methyl + Pretilachlor (10 kg a.i. ha^{-1}) *fb* 2,4-D (1.25 kg a.i. ha^{-1}) + one Hand weeding @ 45 DAS, whereas at 45 DAS, the weed control efficiency of about 71.8 per cent was noticed high in the treatment of Pendimethalin (2.5 kg a.i. ha^{-1}) + Bispyribac sodium (50 g a.i. ha^{-1}) *fb* one Hand weeding @ 45 DAS. This might be due to Pendimethalin belongs to herbicide group dinitroaniline which kill the germinating weeds seeds by mitotic poisoning. The similar treatment was also on par with the treatment of Bensulfuron methyl + Pretilachlor (10 kg a.i. ha^{-1}) *fb* 2,4-D (1.25 kg a.i. ha^{-1}) + one Hand weeding @ 45 DAS during 30 DAS with weed control efficiency of 70.4 per cent. The application of bispyribac sodium was effective against sedges which may be due to its selective and systemic action absorbed by foliage which kills the weeds by causing chlorotic and necrotic symptoms. Among broad leaved weeds, application of Bensulfuron methyl + Pretilachlor (10 kg a.i. ha^{-1}) *fb* 2,4-D (1.25 kg a.i. ha^{-1}) + one hand weeding @ 45 DAS had recorded the highest weed control efficiency of 98.0, 93.0 and 98.8 per cent at 15, 30 and 45 DAS, respectively. This might be due to the effect of 2, 4- D on broad leaved weeds. 2, 4- D is a systemic herbicide which selectively kills the broadleaved weeds by mimicking the action of plant growth hormone auxin. At 60 DAS, no significant differences were noticed in weed control efficiency of herbicidal combinations due to hand weeding at 45 DAS in which late emerging weeds were removed. At 60 DAS, the lowest weed control efficiency of 49.9 (grasses), 50.0 (sedges) and 50.0 (broadleaved weeds) per cent was recorded in the treatment of weedy upto panicle initiation stage.

Weed index

The data on weed index was depicted in table 2. Among sowing methods, the highest weed index of 18.84 was registered in the treatment of medium duration rice variety under puddled condition whereas the lowest weed density of 15.81 and 16.05 was noticed in short duration rice variety under puddled and aerobic condition, respectively.

Among weed management practices, application of Bensulfuron methyl + Pretilachlor (10 kg a.i. ha^{-1}) *fb* 2,4-D (1.25 kg a.i. ha^{-1}) + one hand weeding @ 45 DAS had recorded the lowest weed index of 4.67. This was followed by the treatment of Pendimethalin (2.5 kg a.i. ha^{-1}) + Bispyribac sodium (50 g a.i. ha^{-1}) *fb* one Hand weeding @ 45 DAS and weed free upto active tillering stage with weed index of 7.59 and 8.25, respectively. Whereas the highest weed index of 67.6 was recorded in the treatment of weedy upto panicle initiation stage. The results revealed that the lowest weed index was found in weed free plot as reported by Bangi *et al*. (2014) [2]. Hia *et al*. (2017) [6] reported that the combination of pre emergence and post emergence herbicide will results in lowest weed index.

Grain and straw yield (kg ha^{-1})

The data on grain yield and straw yield was furnished in Fig. 1. Among sowing methods, the highest grain and straw yield were recorded in medium duration rice variety under puddled condition of 4748 kg ha^{-1} and 7288 kg ha^{-1}, respectively. This might be due to reduced weed density under puddled condition limits the crop weed competition and hence increases the yield when compared to aerobic condition. This was in accordance with the findings of Azmi and Johnson (2009) [1].

Among the weed management practices, weed free upto panicle initiation stage recorded the higher grain yield of 5588 kg ha^{-1} and straw yield of 8813 kg ha^{-1}. This was followed by the application of Bensulfuron methyl + Pretilachlor *fb* 2,4-D + 1 Hand weeding @ 45 DAS recorded the grain and straw yield of 5325 kg ha^{-1} and 8166 kg ha^{-1}, respectively. The next best treatment recorded was the application of Pendimethalin (2.5 kg a.i. ha^{-1}) + Bispyribac sodium (50 g a.i. ha^{-1}) *fb* one Hand weeding @ 45 DAS with grain yield and straw yield of 5163 kg ha^{-1} and 7596 kg ha^{-1}, respectively. The results revealed that the usage of single herbicide does not show any significant results hence the combination of either pre emergence and post emergence herbicides or pre emergence and early post emergence herbicides along with one hand weeding was found to be the ideal and cost effective method for weed management under direct seeded condition.

Table 1: Effect of sowing methods and weed management practices on weed density (Nos. m^{-2}) of grasses, sedges and broadleaved weeds

Treatments	Grasses				Sedges				Broadleaved weeds			
	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS
Main plot: Method of sowing												
M_1	5.02 (49.25)	8.30 (101.71)	8.38 (93.71)	4.08 (18.27)	3.30 (14.43)	5.73 (44.95)	5.65 (46.05)	1.23 (1.81)	6.78 (68.10)	6.86 (80.57)	6.19 (70.76)	2.13 (5.05)
M_2	5.03 (49.21)	8.27 (101.90)	9.33 (126.67)	4.97 (52.79)	3.26 (14.31)	5.58 (43.48)	6.87 (65.04)	2.50 (25.10)	6.82 (68.38)	6.94 (80.76)	7.64 (100.56)	3.54 (40.63)
M_3	4.76 (44.30)	6.77 (68.33)	6.22 (51.19)	3.14 (11.00)	2.97 (11.26)	5.19 (37.71)	4.40 (31.48)	0.71 (0.00)	5.07 (38.71)	5.29 (44.67)	5.01 (46.11)	1.93 (3.73)
M_4	4.73 (44.09)	6.83 (68.57)	7.36 (80.14)	4.62 (42.25)	3.03 (11.62)	5.24 (37.62)	5.82 (47.67)	2.24 (18.67)	5.12 (39.25)	5.42 (46.81)	5.97 (58.10)	2.99 (25.76)
SEd	0.10	0.24	0.20	0.13	0.08	0.16	0.15	0.05	0.15	0.17	0.19	0.07
CD	0.24	0.60	0.49	0.32	0.20	0.40	0.36	0.13	0.37	0.41	0.47	0.18

Sub plot: Weed management practices												
S_1	0.71 (0.00)	0.71 (0.00)	3.16 (16.17)	4.48 (23.58)	0.71 (0.00)	0.71 (0.00)	1.12 (1.25)	1.33 (2.42)	0.71 (0.00)	0.71 (0.00)	1.67 (3.42)	2.18 (6.50)
S_2	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.41 (3.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	1.14 (1.00)
S_3	12.41 (153.58)	14.53 (213.17)	9.90 (132.17)	4.13 (17.02)	5.47 (29.67)	9.68 (93.17)	6.20 (62.75)	1.00 (0.75)	10.94 (120.83)	12.56 (159.58)	8.20 (107.78)	1.58 (2.77)
S_4	12.37 (153.48)	14.58 (213.83)	15.37 (238.92)	9.70 (144.17)	5.44 (29.62)	9.72 (93.92)	11.13 (123.25)	6.53 (76.58)	10.96 (121.45)	12.67 (161.25)	14.53 (213.92)	7.76 (110.92)
S_5	2.77 (7.20)	9.03 (82.42)	10.31 (109.67)	3.21 (9.82)	3.73 (13.39)	6.32 (39.83)	8.21 (67.83)	0.71 (0.00)	7.87 (63.17)	9.29 (89.83)	11.27 (128.92)	2.19 (4.35)
S_6	2.47 (5.60)	6.13 (37.50)	7.15 (51.75)	3.22 (9.87)	2.15 (4.13)	5.61 (31.33)	6.54 (42.75)	0.71 (0.00)	2.58 (6.78)	1.39 (1.91)	2.14 (4.17)	1.62 (2.17)
S_7	2.75 (7.11)	6.98 (49.43)	8.16 (67.34)	3.25 (10.08)	3.75 (13.55)	5.20 (26.58)	5.90 (35.12)	0.71 (0.00)	7.92 (63.31)	5.52 (30.83)	4.90 (23.98)	2.06 (3.77)
SEd	0.20	0.28	0.26	0.14	0.15	0.17	0.19	0.07	0.24	0.28	0.32	0.09
CD	0.44	0.61	0.57	0.30	0.33	0.37	0.41	0.16	0.53	0.61	0.69	0.19

Figures in parentheses are original values, subjected to square root transformation ($\sqrt{x} + 0.5$) before statistical analysis. Interaction was non-significant.

Table 2: Effect of sowing methods and weed management on weed control efficiency (%) of grasses, sedges and broadleaved weeds and weed index

Treatments	Grasses				Sedges				Broadleaves				Weed index
	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	15 DAS	30 DAS	45 DAS	60 DAS	
Main plot: Method of sowing													
M_1	69.8	61.6	73.0	99.3	50.8	54.7	67.2	99.9	57.8	55.1	72.4	99.0	16.05
M_2	69.7	61.6	59.3	71.2	50.8	54.7	52.6	85.7	57.8	55.3	58.4	85.4	17.13
M_3	69.6	63.0	74.6	99.4	51.3	53.7	69.6	100.0	58.3	59.2	74.9	99.2	15.81
M_4	69.6	62.9	60.5	71.3	51.3	53.6	55.2	85.7	58.5	59.2	60.9	85.2	18.84
SEd	2.56	2.18	1.85	2.73	1.73	1.72	1.44	2.78	1.83	1.44	1.58	2.29	0.46
CD	NS	NS	4.53	6.69	NS	NS	3.53	6.81	NS	3.52	3.86	5.59	1.12
Sub plot: Weed management													
S_1	100.0	100.0	99.2	98.9	100.0	100.0	99.9	99.9	100.0	100.0	99.3	98.6	8.25
S_2	100.0	100.0	100.0	99.9	100.0	100.0	100.0	100.0	100.0	100.0	100.0	99.9	0.00
S_3	0.0	0.0	49.4	49.3	0.0	0.0	49.9	99.9	0.0	0.0	49.5	99.4	19.37
S_4	0.00	0.0	0.0	49.9	0.0	0.0	0.0	50.0	0.0	0.0	0.0	50.0	67.60
S_5	95.5	67.9	64.2	99.7	36.8	41.5	45.6	100.0	54.4	35.0	32.1	98.9	11.24
S_6	97.1	86.4	80.1	99.7	84.1	67.4	60.9	100.0	98.0	93.0	98.8	99.7	4.67
S_7	95.4	81.8	75.4	99.7	36.5	70.4	71.8	100.0	54.4	72.5	87.1	98.9	7.59
SEd	2.45	2.62	2.32	2.72	1.88	1.66	2.24	2.35	1.86	2.32	2.45	3.78	0.78
CD	5.35	5.70	5.06	5.92	4.10	3.63	4.88	5.11	4.04	5.06	5.35	8.24	1.70

Interaction was non-significant

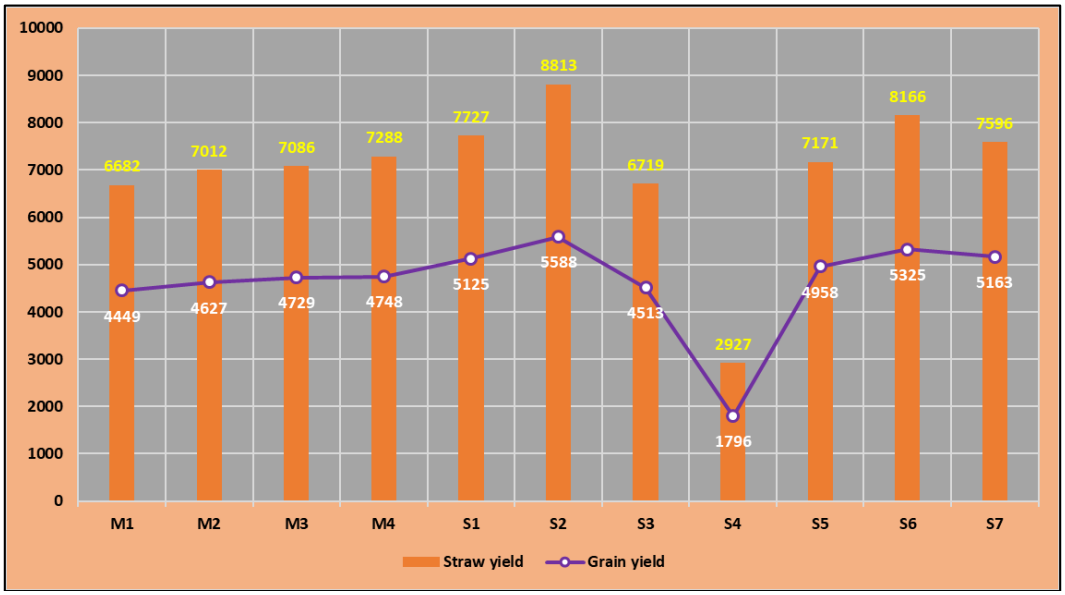

Fig 1: Grain yield (kg ha^{-1}) and straw yield (kg ha^{-1}) of direct seeded rice under puddled and unpuddled conditions

Conclusion

The present study concludes that direct seeded rice was one of the emerging technology to mitigate the water crisis as well as labor shortage and to sustain the rice production if proper weed management is done to reduce the diversified weed flora. In the unweeded check, the yield reduction was noticed

upto 67 per cent. Hence, the pre emergence application of herbicide is must for direct seeded rice and the application of Bensulfuron methyl + Pretilachlor (10 kg a.i. ha^{-1}) *fb* 2,4-D (1.25 kg a.i. ha^{-1}) + one Hand weeding @ 45 DAS was found to be the ideal combination for managing the weeds by increasing weed control efficiency under direct seeded condition with higher grain yield.

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