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Effect of Different Herbicides and Allelochemicals on Weed Density and Soil Microbial Population under Direct Seeded Rice (*Oryza sativa* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The use of herbicides for weed control often catches the eye of environmentalists as it harms the soil microflora leading to deteriorated soil health. So, efforts are being made in order to use herbicides that can cause no or very less harm to the soil microflora. In this context, an experiment is planned to know the potential effect of different herbicides and allelochemicals on weed density and soil microbial population under direct seeded rice where herbicide weed management is widely adopted. The experiment is conducted during *Rabi*, 2020 and summer, 2021 in the red sandy loams of Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bengaluru by using randomized complete block design with three replications. Out of different treatments tried out, T_4 *i.e.*, bispyribac sodium 10 SC 40 g a.i. ha^{-1} as post emergence has reported superior weed control which is evident by the lower weed density (43.3 no. m^{-2}) and weed dry weight (49.2 g m^{-2}) followed

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by T_1 *i.e.*, bensulfuron methyl + pretilachlor 6.6 GR 660 g a.i. ha^{-1} as pre emergence (46.0 no. m^{-2} and 51.4 g m^{-2}, respectively). When soil microbial population is considered all the allelochemical treatments has recorded higher microbial population but the weed control in these allelochemical treatments was not satisfactory. Among the herbicides, T_1 *i.e.*, bensulfuron methyl + pretilachlor 6.6 GR 660 g a.i. ha^{-1} as pre emergence has recorded higher microbial population of bacteria, actinomycetes and fungi (23.52 x 10^5, 15.30 x 10^4 and 12.45 x 10^3 CFU g^{-1} soil, respectively) over T_4 *i.e.*, bispyribac sodium 10 SC 40 g a.i. ha^{-1} as post emergence (21.83 x 10^5, 13.33 x 10^4 and 10.91 x 10^3 CFU g^{-1} soil, respectively). Hence, by taking both weed control and soil microbial population into consideration treatment T_1 *i.e.*, bensulfuron methyl + pretilachlor 6.6 GR 660 g a.i. ha^{-1} as pre emergence is concluded to be the better herbicide.

Keywords: Herbicides; allelochemicals; weed density; microbial population; direct seeded rice.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops, providing a staple diet for more than half of the global population. Rice is the most important source of food in India, providing 43 per cent of the calorie requirements for more than two-thirds of the population [1] and 55 per cent of cereal production in the country. Herbicides are considered to be the most extensively used pesticides globally. With the introduction of herbicides in 19th century, weed control has become less of a chore and more energy efficient [2]. Because of their cost and time effectiveness, chemical weed control has become the most widely used weed control tool all over the world.

Direct seeding of rice eliminates the nursery raising and transplanting operations, faster and easier planting, reduces labour requirement, hastens crop maturity and increased water use efficiency, thus 25 per cent (250-300 man hours) of total human labour involved in rice cultivation were reduced making rice cultivation more economical [3]. As weeds arise almost simultaneously as that of the crop in the direct seeded rice the weed competition with rice crop is greater, hence weed management by herbicide is more crucial [4]. Weeds pose a major threat in DSR by competing for nutrients, light, space and moisture with the crop just from the time of emergence and throughout the growing season. Hence, weed management by using herbicides becomes necessary. But, the application of chemical herbicides not only kills the weeds but also harms the soil microflora impacting the soil health [5]. During many instances, the effect of agrochemicals on the soil microflora is neglected.

Keeping these points in view the current research is planned to investigate the effect of different chemical herbicides and allelochemical on weed control and soil microflora under direct seeded rice.

2. MATERIALS AND METHODS

A field investigation was carried out during *Rabi*, 2020 and Summer, 2021 in the red sandy loams of Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences, Bengaluru, Karnataka (12º 58' N, 77º 33' E). The field experiment was laid out in RCBD replicated thrice with twelve treatments including both chemical herbicides and aqueous extracts of allelochemicals. The treatment details were T_1: Bensulfuron methyl + Pretilachlor 6.6 G 660 g a.i. ha^{-1} as pre-emergence; T_2: Pyrazosulfuron ethyl 10 WP 40 g a.i. ha^{-1} as pre-emergence; T_3: Oxadiargyl 80 WP 100 g a.i. ha^{-1} pre-emergence; T_4: Bispyribac sodium 10 SC 40 g a.i. ha^{-1} as post emergence; T_5: Quizolofop-p-ethyl 15 EC 37.5 g a.i. ha^{-1} as post emergence; T_6: Cyhalofop-p-butyl 10 EC 100 g a.i. ha^{-1} as post emergence; T_7: Metamifop 10 EC 100 g a.i. ha^{-1} as post emergence; T_8: *Leucas aspera* plant extract; T_9: *Eucalyptus* leaf extract; T_{10}: *Hyptis saveolensis* plant extract; T_{11}: Hand weeding at 20 and 40 DAS and T_{12}: Unweeded control.

The herbicides were applied by using a hydraulic knapsack sprayer having flood jet nozzle. The spray volume used was 750 L ha^{-1} for pre emergent herbicides and 500 L ha^{-1} for post emergent herbicides. Pre emergence application was carried out at 0-3 DAS and post emergent application at 20 DAS. Whereas, the aqueous allelochemical plant extracts were applied at 10 % w/v as post emergence application. For aqueous allelochemical extract preparation a 10 g of plant sample was weighed and blended by slowly adding 100 ml of distilled water. The blended solution was first filtered through a double layered muslin cloth and then through Whatman No. 1 filter paper. The obtained 10 % (w/v) aqueous allelochemical extract was used for spraying [6].

Weed densities were estimated by taking two 0.25 m^2 quadrate samples at random locations within each plot and then they were converted into weeds per m^2. For weed biomass estimation all the weeds existing in 0.25 m^2 quadrant sample of each plot were cut to the soil surface level, placed in paper bags and dried in a hot air oven at 60 ^oC until a constant dry weight was recorded and the final dry weight was converted to g m^{-2}. The data pertaining to weed was transformed before subjecting to ANOVA [7].

The soil microbial populations were estimated from the soil samples collected at harvest (135 DAS) at 0-15 cm depth. The rhizosphere soil samples collected from experimental soil were analyzed for the different soil microorganisms *viz*., total bacteria, fungi and actinomycetes using standard dilution plate count technique and plating on the specific nutrient media. Collected soil samples were mixed thoroughly and subjected to serial dilution by using 1 g of soil in 100 ml of the distilled water. The enumeration of microorganisms was done after culturing these organisms using the different media by standard dilution plate technique. The media used were soil extract agar media for bacteria, Martins Rose Bengal agar with streptomycin sulphate for fungi and Kusters agar media for actinomycetes. The number of colonies were counted and multiplied by the dilution factor for the concerned group and expressed as number of colony farming units (CFU) per gram of the dry soil [8].

All the data were analyzed and the results are presented and discussed at a probability level of 5%.

3. RESULTS AND DISCUSSION

3.1 Weed Species

The major sedge observed in the experimental field in association with direct seeded rice was *Cyperus rotundus* and the grasses were *Cynodon dactylon, Digitaria sanguinalis, Echinochloa colona, Eleusine indica* and *Panicum repens*. The broad leaf weeds observed were *Alternanthera sessilis, Amaranthus viridis, Borreria hispida, Cassia sp., Euphorbia geniculata, Ipomea alba* and *Mollugo disticha*. The other weeds observed in less numbers were *Dactyloctenium aegyptium* (grass), *Ageratum conyzoides, Portulaca oleracia* and *Phyllanthus niruri* (broad leaf weeds). Similar kind of weed flora dominated by grasses were also reported by many researchers working on direct seeded rice [9,10].

3.2 Weed Density

Among all the herbicide treatments, significantly lower density of sedges were observed in T_1 *i.e*., bensulfuron methyl + pretilachlor 6.6 GR 660 g a.i. ha^{-1} as pre emergence (6.7 m^{-2}) compared to all other treatments except T_4 (7.4 m^{-2}) with which it was at par (Table 1). Significantly lower density of grassy weeds was recorded with T_7 *i.e*., metamifop 10 EC 100 g a.i. ha^{-1} as post emergence (14.3 m^{-2}) as compared to other herbicide treatments but was found at par with T_5 (15.6 m^{-2}), T_6 (16.7 m^{-2}) and T_4 (18.3 m^{-2}). The broad leaf weeds density was significantly lower in T_4 *i.e*., bispyribac sodium 10 SC 40 g a.i. ha^{-1} as post emergence (17.6 m^{-2}) compared to other herbicide treatments except T_1 (19.0 m^{-2}), T_2 (21.0 m^{-2}) and T_3 (22.3 m^{-2}) with which it was statistically on par.

With respect to total weed density, T_4 *i.e*., bispyribac sodium 10 SC 40 g a.i. ha^{-1} as post emergence (43.3 m^{-2}) was found to be at par with T_1 *i.e*., bensulfuron methyl + pretilachlor 6.6 GR 660 g a.i. ha^{-1} as pre emergence (46.0 m^{-2}). Bispyribac sodium is a broad spectrum systemic herbicide having selectivity to rice and can control major grasses, sedges and broad leaf weeds of rice, hence it has recorded lowest total weed density [11,12]. Among different treatments, application of chemical herbicides has resulted in better reduction in weed density compared to allelochemicals.

Among all the treatments, T_{11} *i.e*., hand weeding at 20 and 40 DAS has recorded lowest sedge, grass, broad leaf and total weed density and T_{12} *i.e*., unweeded control has recorded higher sedge, grass, broad leaf and total weed density [13].

3.3 Weed Dry Weight

Weed dry weight is a measure of weed hardiness and its ability to compete with the crop (Table 2).

Table 1. Category wise weed density (number m^{-2}) at harvest in direct seeded rice as influenced by different weed management practices

Treatments	Sedges			Grasses			Broad leaf weeds			Total weeds		
	2020+	2021+	Pooled+	2020#	2021#	Pooled#	2020#	2021#	Pooled#	2020#	2021#	Pooled#
T_1	2.88(7.3)	2.65(6.0)	2.76(6.7)	1.36(20.7)	1.34(20.0)	1.35(20.4)	1.33(19.4)	1.31(18.6)	1.32(19.0)	1.69(47.4)	1.67(44.6)	1.68(46.0)
T_2	3.21(9.3)	3.00(8.0)	3.11(8.7)	1.38(22.0)	1.37(21.3)	1.37(21.7)	1.37(21.3)	1.35(20.6)	1.36(21.0)	1.74(52.7)	1.72(49.9)	1.73(51.3)
T_3	3.32(10.0)	3.11(8.7)	3.22(9.4)	1.42(24.6)	1.40(23.3)	1.41(24.0)	1.39(22.6)	1.38(22.0)	1.39(22.3)	1.77(57.2)	1.75(54.0)	1.76(55.6)
T_4	3.00(8.0)	2.77(6.7)	2.89(7.4)	1.33(19.3)	1.29(17.3)	1.31(18.3)	1.30(18.0)	1.29(17.3)	1.29(17.6)	1.67(45.3)	1.64(41.3)	1.66(43.3)
T_5	4.28(17.3)	4.12(16.0)	4.20(16.7)	1.27(16.6)	1.22(14.6)	1.24(15.6)	1.60(38.0)	1.57(35.3)	1.59(36.6)	1.87(71.9)	1.83(65.9)	1.85(68.9)
T_6	4.12(16.0)	3.96(14.7)	4.04(15.4)	1.29(17.3)	1.26(16.0)	1.27(16.7)	1.54(32.6)	1.50(29.4)	1.52(31.0)	1.83(66.0)	1.79(60.2)	1.81(63.1)
T_7	4.04(15.3)	3.87(14.0)	3.96(14.7)	1.24(15.3)	1.18(13.3)	1.21(14.3)	1.55(33.3)	1.52(31.3)	1.54(32.3)	1.82(63.9)	1.78(58.6)	1.80(61.3)
T_8	3.87(14.0)	3.70(12.7)	3.79(13.4)	1.66(43.3)	1.63(40.7)	1.64(42.0)	1.51(30.0)	1.48(28.0)	1.49(29.0)	1.95(87.3)	1.92(81.4)	1.94(84.3)
T_9	3.78(13.3)	3.61(12.0)	3.69(12.7)	1.58(36.0)	1.55(33.3)	1.56(34.6)	1.44(25.3)	1.40(23.4)	1.42(24.3)	1.88(74.6)	1.85(68.7)	1.87(71.6)
T_{10}	3.87(14.0)	3.70(12.7)	3.79(13.4)	1.60(38.0)	1.58(36.0)	1.59(37.0)	1.47(27.3)	1.46(26.7)	1.46(27.0)	1.91(79.4)	1.89(75.4)	1.90(77.4)
T_{11}	2.52(5.3)	2.39(4.7)	2.45(5.0)	1.10(10.7)	1.05(9.3)	1.08(10.0)	1.21(14.1)	1.17(12.7)	1.19(13.4)	1.51(30.1)	1.46(26.7)	1.48(28.4)
T_{12}	4.72(21.3)	4.51(19.3)	4.61(20.3)	1.90(77.3)	1.88(74.6)	1.89(76.0)	1.78(58.0)	1.76(56.1)	1.77(57.1)	2.20(156.6)	2.18(150.0)	2.19(153.3)
S.Em±	0.13	0.10	0.11	0.04	0.04	0.04	0.03	0.04	0.03	0.02	0.03	0.02
CD (P=0.05)	0.38	0.28	0.33	0.11	0.11	0.11	0.09	0.11	0.10	0.06	0.08	0.07

Data within the parentheses are original values; Transformed values - # = log (x+2), + = square root of (x+1)

T_1: Bensulfuron methyl + pretilachlor 6.6 GR @ 660 g a.i. ha^{-1} as pre emergence; T_2: Pyrazosulfuron ethyl 10 WP @ 40 g a.i. ha^{-1} as pre emergence; T_3: Oxadiargyl 80 WP @ 100 g a.i. ha^{-1} pre emergence; T_4: Bispyribac sodium 10 SC @ 40 g a.i. ha^{-1} as post emergence; T_5: Quizalofop-p-ethyl 5 EC @ 37.5 g a.i. ha^{-1} as post emergence; T_6: Cyhalofop-p-butyl 10 EC @ 100 g a.i. ha^{-1} as post emergence; T_7: Metamifop 10 EC @ 100 g a.i. ha^{-1} as post emergence; T_8: Leucas aspera plant extract; T_9: Eucalyptus leaf extract; T_{10}: Hyptis suaveolens plant extract; T_{11}: Hand weeding at 20 and 40 DAS; T_{12}: Unweeded control

Table 2. Category wise weed dry weight (g m^{-2}) at harvest in direct seeded rice as influenced by different weed management practices

Treatments	Sedge			Grasses			Broad leaf weeds			Total weeds		
	2020+	**2021+**	**Pooled+**	**2020#**	**2021#**	**Pooled#**	**2020#**	**2021#**	**Pooled#**	**2020#**	**2021#**	**Pooled#**
T_1	3.65(12.3)	3.59(11.9)	3.62(12.1)	1.40(23.0)	1.39(22.3)	1.39(22.6)	1.30(17.9)	1.24(15.3)	1.27(16.6)	1.74(53.3)	1.71(49.5)	1.73(51.4)
T_2	3.84(13.7)	3.71(12.8)	3.78(13.3)	1.47(27.6)	1.38(22.1)	1.43(24.9)	1.33(19.3)	1.27(16.6)	1.30(17.9)	1.80(60.6)	1.73(51.5)	1.76(56.1)
T_3	3.93(14.5)	3.84(13.7)	3.89(14.1)	1.51(30.2)	1.42(24.6)	1.47(27.4)	1.38(22.1)	1.35(20.5)	1.37(21.3)	1.84(66.8)	1.78(58.8)	1.81(62.8)
T_4	3.75(13.1)	3.72(12.9)	3.74(13.0)	1.38(22.1)	1.34(20.1)	1.36(21.1)	1.25(15.8)	1.22(14.5)	1.23(15.1)	1.72(50.9)	1.69(47.4)	1.71(49.2)
T_5	5.19(26.0)	5.09(24.9)	5.14(25.4)	1.33(19.3)	1.26(16.1)	1.29(17.7)	1.59(37.0)	1.57(35.3)	1.58(36.2)	1.93(82.3)	1.89(76.3)	1.91(79.3)
T_6	4.91(23.1)	4.72(21.3)	4.82(22.2)	1.36(21.1)	1.31(18.4)	1.34(19.7)	1.53(32.2)	1.50(29.9)	1.52(31.1)	1.89(76.4)	1.85(69.6)	1.87(73.0)
T_7	4.75(21.5)	4.54(19.6)	4.65(20.6)	1.26(16.3)	1.24(15.3)	1.25(15.8)	1.58(35.8)	1.54(32.6)	1.56(34.2)	1.88(73.7)	1.84(67.5)	1.86(70.6)
T_8	4.49(19.2)	4.12(16.0)	4.31(17.6)	1.68(45.7)	1.64(41.8)	1.66(43.7)	1.55(33.8)	1.51(30.5)	1.53(32.1)	2.00(98.7)	1.96(88.2)	1.98(93.5)
T_9	4.14(16.2)	3.95(14.6)	4.05(15.4)	1.64(41.7)	1.61(39.0)	1.63(40.3)	1.49(28.7)	1.45(26.2)	1.47(27.5)	1.95(86.5)	1.91(79.8)	1.93(83.2)
T_{10}	4.27(17.2)	4.11(15.9)	4.19(16.6)	1.66(44.2)	1.63(40.5)	1.65(42.3)	1.52(31.5)	1.49(28.9)	1.51(30.2)	1.98(92.80	1.94(85.3)	1.96(89.1)
T_{11}	3.49(11.2)	3.40(10.5)	3.44(10.9)	1.22(14.7)	1.20(13.8)	1.21(14.3)	1.16(12.5)	1.14(11.7)	1.15(12.1)	1.61(38.4)	1.58(36.1)	1.59(37.3)
T_{12}	5.89(33.7)	5.58(30.2)	5.74(32.0)	1.89(75.3)	1.87(71.7)	1.88(73.5)	1.85(68.1)	1.81(62.5)	1.83(65.3)	2.25(177.2)	2.22(164.4)	2.24(170.8)
S.Em±	0.09	0.11	0.10	0.04	0.03	0.04	0.03	0.02	0.02	0.02	0.01	0.02
CD (P=0.05)	0.28	0.32	0.30	0.12	0.10	0.11	0. 08	0.06	0.07	0.07	0.03	0.06

Data within the parentheses are original values; Transformed values - # = log (x+2), + = square root of (x+1).

T_1: Bensulfuron methyl + pretilachlor 6.6 GR @ 660 g a.i. ha^{-1} as pre emergence; T_2: Pyrazosulfuron ethyl 10 WP @ 40 g a.i. ha^{-1} as pre emergence; T_3: Oxadiargyl 80 WP @ 100 g a.i. ha^{-1} pre emergence; T_4: Bispyribac sodium 10 SC @ 40 g a.i. ha^{-1} as post emergence; T_5: Quizalofop-p-ethyl 5 EC @ 37.5 g a.i. ha^{-1} as post emergence; T_6: Cyhalofop-p-butyl 10 EC @ 100 g a.i. ha^{-1} as post emergence; T_7: Metamifop 10 EC @ 100 g a.i. ha^{-1} as post emergence; T_8: Leucas aspera plant extract; T_9: Eucalyptus leaf extract; T_{10}: Hyptis suaveolens plant extract; T_{11}: Hand weeding at 20 and 40 DAS; T_{12}: Unweeded control

Table 3. Soil microbial population after harvest in direct seeded rice as influenced by different weed management practices

Treatments	Bacteria ($\times 10^5$ CFU g^{-1} soil)			Fungi ($\times 10^4$ CFU g^{-1} soil)			Actinomycetes ($\times 10^3$ CFU g^{-1} soil)		
	2020	**2021**	**Pooled**	**2020**	**2021**	**Pooled**	**2020**	**2021**	**Pooled**
T_1: Bensulfuron methyl + pretilachlor 6.6 GR @ 660 g a.i. ha^{-1} as pre emergence	22.57	24.47	23.52	14.74	15.87	15.30	11.95	12.94	12.45
T_2: Pyrazosulfuron ethyl 10 WP @ 40 g a.i. ha^{-1} as pre emergence	21.42	23.36	22.39	13.27	14.67	13.97	10.71	11.83	11.27
T_3: Oxadiargyl 80 WP @ 100 g a.i. ha^{-1} pre emergence	21.96	23.51	22.73	14.30	15.52	14.91	11.50	12.49	11.99
T_4: Bispyribac sodium 10 SC @ 40 g a.i. ha^{-1} as post emergence	20.97	22.70	21.83	12.67	14.00	13.33	10.41	11.40	10.91
T_5: Quizalofop-p-ethyl 5 EC @ 37.5 g a.i. ha^{-1} as post emergence	19.36	20.30	19.83	9.86	10.76	10.31	9.33	9.64	9.48
T_6: Cyhalofop-p-butyl 10 EC @ 100 g a.i. ha^{-1} as post emergence	19.96	21.85	20.91	10.30	11.29	10.79	9.65	10.28	9.97
T_7: Metamifop 10 EC @ 100 g a.i. ha^{-1} as post emergence	20.46	22.42	21.44	11.83	12.95	12.39	10.21	10.91	10.56
T_8: *Leucas aspera* plant extract	22.98	24.91	23.94	15.20	16.35	15.77	12.29	13.15	12.72
T_9: *Eucalyptus* leaf extract	23.35	25.29	24.32	15.95	16.71	16.33	12.92	13.69	13.30
T_{10}: *Hyptis suaveolens* plant extract	23.08	24.85	23.96	15.48	16.01	15.75	12.57	13.19	12.88
T_{11}: Hand weeding at 20 and 40 DAS	23.89	25.64	24.77	16.13	17.42	16.78	13.05	14.11	13.58
T_{12}: Unweeded control	22.24	24.14	23.19	14.48	15.55	15.01	11.83	12.76	12.30
S. Em±	0.67	0.75	0.71	0.61	0.65	0.63	0.52	0.54	0.53
CD (P=0.05)	2.01	2.24	2.13	1.84	1.96	1.90	1.57	1.63	1.60

Among all the herbicide treatments, lower weed dry weight of sedges was recorded in T_1 *i.e*., bensulfuron methyl + pretilachlor 6.6 GR 660 g a.i. ha^{-1} as pre emergence (12.1 g m^{-2}) and was at par with T_4 (13.0 g m^{-2}), T_2 (13.3 g m^{-2}) and T_3 (14.1 g m^{-2}) with which it was at par. Significantly lower weed dry weight of grassy weeds was recorded with T_7 *i.e*., metamifop 10 EC 100 g a.i. ha^{-1} as post emergence (15.8 g m^{-2}) and was found at par with T_5 (1 17.7 g m^{-2}), T_6 (19.7 g m^{-2}) and (21.1 g m^{-2}). The broad leaf weeds dry weight was significantly lower in T_4 *i.e*., bispyribac sodium 10 SC 40 g a.i. ha^{-1} as post emergence (15.1 g m^{-2}) and was at par with T_1 (16.6 g m^{-2}) and T_2 (17.9 g m^{-2}) with which it was statistically on par.

With respect to total weed dry weight, T_4 *i.e*., bispyribac sodium 10 SC 40 g a.i. ha^{-1} as post emergence recorded significantly lower weed dry weight (49.2 g m^{-2}) and was on par with T_1 (51.4 g m^{-2}). Any herbicide which targets all the three category of weeds will undoubtedly record lower total weed dry weight. In line with this, herbicide bispyribac sodium was reported to control all the categories of weeds *viz*., grasses, broad leaf weeds and sedges. Because of this broad spectrum weed control it has recorded lower total weed dry weight (8). Similarly, bensulfuron methyl + pretilachlor is also a broad spectrum herbicide which can control grasses, broad leaved weeds and sedges. Hence, it also recorded lower total weed dry weight after bispyribac sodium. Among herbicidal treatments, application of chemical herbicides has resulted in better reduction in weed dry weight compared to allelochemical plant extracts. This might be due to their lesser efficiency, lower residual nature when compared to synthetic chemical herbicides.

Among all the treatments, T_{11} *i.e*., hand weeding at 20 and 40 DAS has recorded lowest sedge, grass, broad leaf and total weed dry weight and T_{12} *i.e*., unweeded control has recorded higher sedge, grasses, broad leaf and total weed dry weight [14].

3.4 Soil Microbial Population

Soil microorganisms play a key role in the soil biological processes [15]. Soil microbial population will quickly respond to disturbances like addition of chemical fertilizers and pesticides in a shorter span of time. So, soil microbial activity is used as a potential indicator of soil biological quality especially when chemicals (pesticides) are applied because of their rapid response to the input added in crop management system. Different weed management practices have significantly influenced the population of bacteria, fungi and actinomycetes (Table 3).

At harvest, significantly higher population of bacteria (24.77 x 10^5 CFU g^{-1} soil), fungi (16.78 x 10^4 CFU g^{-1} soil) and actinomycetes (13.58 x 10^3 CFU g^{-1} soil) was recorded with hand weeding at 20 and 40 DAS (T_{11}) and was found to be statistically at par with all three allelochemical treatments *i.e*., T_9 *i.e*., *Eucalyptus* leaf extract (24.32 x 10^5, 16.33 x 10^4, 13.30 x 10^3 CFU g^{-1} soil, respectively), T_{10} *i.e*., *Hyptis suaveolens* plant extract (23.96 x 10^5, 15.75 x 10^4, 12.88 x 10^3 CFU g^{-1} soil, respectively), T_8 *i.e*., *Leucas aspera* plant extract (23.94 x 10^5, 15.77 x 10^4, 12.72 x 10^3 CFU g^{-1} soil, respectively) and herbicide treatments, T_1 *i.e*., bensulfuron methyl + pretilachlor 6.6 GR 660 g a.i. ha^{-1} as pre emergence (23.52 x 10^5, 15.30 x 10^4, 12.45 x 10^3 CFU g^{-1} soil, respectively) and T_3 *i.e*., oxadiargyl 80 WP 100 g a.i. ha^{-1} as pre emergence (22.73 x 10^5, 14.91 x 10^4, 11.99 x 10^3 CFU g^{-1} soil, respectively).

Allelochemicals being natural compounds, their degradation is rapid and hence did not affect the microbial load of soil. Application of bensulfuron methyl + pretilachlor and oxadiargyl also reported higher microbial populations [16,17]. Whereas, the herbicides pyrazosulfuron ethyl and bispyribac sodium recorded lower microbial population mainly because of higher dosage of application i.e., 40 g a.i ha^{-1}. Significantly, lowest bacteria, fungi and actinomycetes population was reported with T_5 *i.e*., quizalofop-p-ethyl 5 EC 37.5 g a.i. ha^{-1} (19.83 x 10^5, 10.31 x 10^4, 9.48 x 10^3 CFU g^{-1} soil, respectively) due to its high persistence and fairly slow decomposition of herbicide in soil.

4. CONCLUSION

With respect to weed control in direct seeded rice T_4 *i.e*., bispyribac sodium 10 SC 40 g a.i. ha^{-1} as post emergence reported significantly lower weed density (43.3 no. m^{-2}) and weed dry weight (49.2 g m^{-2}) but, the herbicide has reduced the soil microbial population significantly. Even though allelochemical treatments were superior with respect to soil microbial population, the weed control was not satisfactory. Hence the treatment T_1 *i.e*., bensulfuron methyl + pretilachlor 6.6 GR 660 g a.i. ha^{-1} as pre emergence which recorded satisfactory weed control with somewhat lower weed density and dry weight (46.0 no. m^{-2} and 51.4 g m^{-2}, respectively) along with better microbial population of bacteria, fungi and actinomycetes (23.52 x 10^5, 15.30 x 10^4 and 12.45 x 10^3 CFU g^{-1} soil, respectively) can be recommended for the sustainable weed management in direct seeded rice.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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