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Impact of aerobic rice-leafy vegetables intercropping systems on weed management

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Abstract: Field experiments were carried out in summer 2017 and 2018 at Zonal Agricultural Research Station (ZARS), University of Agricultural Sciences, GKVK, Bengaluru, India on red sandy loam soil. The main objective was to evaluate the impact of rice grown in aerobic conditions intercropped with leafy vegetables on weed management, wherein the sole rice and intercrops of four leafy vegetables: palak (*Spinacia oleracea* L.), coriander (*Coriandrum sativum* L.), amaranth (*Amaranthus spp* L.), methi (*Trigonella foenum-graecum* L.) were designed in randomized complete block design (RCBD) of 9 treatments replicated four times. The results revealed that the greater the crop biomass, the higher the weed suppression achieved. Sole rice was densely populated by weeds and also had higher weed biomass compared to the intercrops. However, intercrops suppressed efficiently the weeds, increased growth and rice equivalent yield over the sole rice crop. The intercropping systems with leafy palak (spinach) were the most suppressive of weeds. The rice + leafy vegetable palak recorded significantly lower weed density (138.4 no. m^{-2}), dry weight at harvest (148.04 g m^{-2}), higher rice grain, rice straw and palak leaf yield (7651; 9687 and 25508 kg ha^{-1}, respectively) and higher net monetary return (₹ 156269 ha^{-1}) over the sole rice.

1. Introduction

The rice is the world most important staple food for more than a half of the earth's population. It contains high amount of carbohydrates, proteins and calories. More than 90 per cent of rice is cultivated and consumed in Asia, where more than 60 per cent of the world's population lives.

According to FAO, the world rice consumption demand increases as the population increases too. By 2025, the amount of 800 M t of rice grain will be needed for consumption, which is a bit higher than the current rice grain production of 718 M t. The rice production is facing several challenges such as population explosion, urbanization, industrialization, shrinkage of cultivable land, water resources, etc., which make difficult to meet the rice food production demand. Increasing the rice productivity per unit area is the need of the hour to bridge the gap between production and consumption.

The production of rice in aerobic condition by using the same production method used for other rain fed cereals like maize, wheat, etc., can be one of the resorts to mitigate the challenges. The rice grown in aerobic conditions known as aerobic rice provides several benefits of saving the inputs and human labour resources and reduces the greenhouse gases among the others. However, this rice production system faces a lot of problems including the weed infestation since the weed competition for resources starts from day one. Weeds can reduce the production of rice by 10-100% (Rao *et al*., 2014; Yaduraju *et al.,* 2015). Controlling weeds satisfactorily increases the cost of cultivation of the crop as well as deplete resource base (Buriro *et al.,* 2003). Reduced weed biomass in intercropping systems has been reported by several workers in various field crops such as soybean, maize, sorghum, sunflower, green gram, red gram, groundnut, etc., but they did not explore yet the leafy vegetables as intercrops. There must be continuing attention paid to study the weed dynamics and crop-weed interference in intercropping systems with smother leafy vegetables. More information is needed concerning crop diversification on weed dynamics and weed flora and differential resources consumption by crops and associated weeds.

Most of the farmers of the developing world are small, marginal and are unable to bear the high costs associated in carrying out weed management operations. Chemical weed control creates many problems such as development of herbicide resistant weeds, shifting weed flora and environmental pollution. The crop diversity can improve crop growth (Kirkegaard and Hunt, 2010), thus increasing crop competitiveness and tolerance to weeds (Anderson, 2011). Cropping systems composed of a diversity of crops with different life cycles are a great option to manage weeds and critical component of integrated weed management (Colbach *et al.,* 2014). To ensure safeguard against environmental pollution and to reduce chances of shifting of weed flora and the development of herbicide-resistant weeds, an intercropping system which allows minimum weed infestation and yield losses, appear to have great importance. Although intercropping is practiced to maximize land use, it has also a significant effect in suppressing weed growth. But intercropping system alone is not sufficient to ensure adequate weed management practices, because of diverse canopy coverage occurred by intercrop.

Labour is becoming a scarce and costly input in agriculture. This has resulted in increased technical grade herbicide consumption. Hence, the present thrust in weed studies is to minimize the herbicide use and to formulate integrated management practices by combining non-chemical methods, which are efficient, economically viable and eco-friendly sound. Therefore, based on this background, the field experiments were planned.

2. Materials and Methods

Field experiments were carried out in summer seasons of 2017 and 2018 at Zonal Agricultural Research Station (ZARS), University of Agricultural Sciences, GKVK, Bengaluru, India on red sandy loam soil to evaluate the performance of leafy vegetables smothering efficiency in weed management.

Experimental design and treatment details

The experiment had RCBD design which was composed of 9 treatments replicated 4 times. The treatments included the four of rice intercropped with 4 leafy vegetables namely Rice + amaranth, Rice + coriander, Rice + palak (spinach) and Rice + methi (fenugreek) and the 5 treatments of sole crops including sole rice crop and 4 sole vegetable crops. The experimental site had pH (6.93), EC (0.36 dSm^{-1}), medium in organic carbon (0.58 %), available nitrogen (362 kg ha^{-1}), P_2O_5 (43 kg ha^{-1}) and K_2O (289 kg ha^{-1}).

Land preparation and layout

During January and February 2017, December 2017 and January 2018 the land was tilled with tractor-drawn cultivator followed by passing rotovator to bring the soil to the fine tilth. The plots were arranged as per the experimental design with 50 cm width bunds around each plot.

The gross plot size was 5 m x 3.5 m (17.5 m^2) accommodating 20 rows at a spacing of 25 cm, each row consisted 20 hills of rice plants with an intra-row spacing of 25 cm. One side row and one adjacent row on each side were left as border rows and the remaining 4 m x 2.5 m (10.00 m^2) was retained as the net plot. The spacing between plots and replications were 0.5 m and 1 m, respectively.

Fertilizers application

The recommended dose of farmyard manure (FYM) at 10 t ha^{-1} was applied 15 days prior to sowing and fertilizer dose of 100: 50: 50 kg N, P_2O_5, K_2O ha^{-1}

was applied through urea, single superphosphate (SSP) and Muriate of potash (MoP), respectively. The 50 per cent of N was applied as basal dose and remaining 50 per cent was applied in two splits *i.e.,* at tillering and panicle initiation stage of the rice crop. Whereas, SSP and MoP fertilizers were applied as basal dose at the time of sowing. For all intercrops, only recommended dose fertilizer of base crop was used.

Seeds and sowing

Shallow furrows spaced at 25 cm apart were created using marker during summer 2017 and 2018. The aerobic rice variety used was MAS 946-1. Two rice seeds per spot were dibbled by maintaining the inter and intra row spacing of 25 cm with a seed rate of 7 kg ha^{-1} on 8th March and 13th January for 2017 and 2018, respectively. The leafy vegetable seeds were sowed by the broadcasting method. Amaranth variety used for sowing was Arka suguna, seed rate used for broadcasting was 2.5 kg ha^{-1}. Coriander variety used was DWD-3, seed rate 10 kg ha^{-1} for broadcasting and duration of the crop was 30 days for vegetable and 90 days for grain. It provides green leaf productivity of 15 t ha^{-1}. Palak variety used was Pusa Jyoti with the yield over 200 to 400 quintals per hectare, seed rate used for broadcasting was 13 kg ha^{-1}. Methi variety used was Co-1 variety; seed rate used for broadcasting was 12 kg ha^{-1}. It provides green leaf productivity of 20 t ha^{-1}. The seeds were covered with soil and gently compacted. Irrigation was provided immediately after sowing to encourage uniform germination.

Irrigation

Irrigation was scheduled at 3-4 days interval through drip based on the rainfall, soil and crop appearance during the crop periods. Drip irrigation system was set out which included the pump, filter units, mainline and sub-main lines for each replication and laterals for each plot. The water source was a bore well. Water was pumped through 7.5 HP motor it was conveyed to the main field using 90 mm PVC pipes after filtering through sand and screen filter. From the mainline water was taken to the field through sub-main of 63 mm diameter PVC pipes. From the sub-main, 12 mm laterals were fixed at a spacing of 50 cm. The emitters in the inline laterals were fixed at 40 cm. The discharge rate of emitters was 3 lph. Irrigation was withheld 10 days before the crop attained maturity.

Weed management

Weeds were controlled by manual cleaning. Weed density and weed dry weight were recorded category wise with respect to grassy, broad leaved weeds and sedge weeds at 30, 60, 90 DAS and at harvest. Weed density was recorded in 0.5 m × 0.5 m quadrate randomly at one spot in each plot. Weeds were uprooted, washed with tap water, sun-dried, oven-dried at 65°C for 48 h. After attaining the constant weight, the samples were weighed and expressed in grams per m^2. The weed smothering efficiency (WSE) was worked out by following the below formula:

$$\text{WSE (per cent)} = \frac{(W1-W2)}{W1} \times 100$$

Where, W_1: Weed dry weight in sole rice crop stand plots; W_2: Weed dry weight in intercropped leafy vegetable plots

Uptake of nutrients nitrogen, phosphorus and potassium by weeds and different parts of paddy and leafy vegetables were calculated by multiplying the nutrient content and dry matter of weeds or yield of plant part using the following formula and expressed in kg ha^{-1}.

$$\text{Nutrient uptake by weed} = \frac{\text{Nutrient content (per cent) x weed DW (kg ha}^{-1})}{100}$$

$$\text{Nut. uptake by rice plant} = \frac{\text{Nutr. cont. (per cent) x Biological yield (kg ha}^{-1})}{100}$$

Rice and vegetable intercrops harvest

The rice crop was harvested on 28thJuly, 2017 and on 14th June 2018 as the ear heads changed into brown color coupled with yellow colored straw in more than 90 per cent of plant population of each plot. All borderlines in every treatment plot were harvested as bulk by leaving net plot area. Later, the net plot area was harvested treatment-wise separately by cutting at 2 inches above the ground, sun-dried for 3 days and threshed. The harvested produce was threshed manually. The grains were winnowed; sun-dried to bring the moisture up to 10-12 per cent and recorded the grain weight treatment-wise. The rice grain and straw dry weight from the net plot was recorded and expressed as kg ha^{-1}. The threshed straw was left in the same field and same plot for sun drying for 10 days. The weight of straw was also recorded treatment-wise and computed for hectare basis. Regarding the leafy vegetables, before harvesting between 30-40 days after sowing, 5 plant samples were taken for dry weight; thereafter the whole plot leaves were harvested, weighed and sold for consumption purpose.

Index of biological efficiencies of intercropping systems

Different system productivity parameters of intercropping systems were worked out. The below are the formulas used.

The Land Equivalent Ratio (LER) is used to decide which crop is suitable among the intercropping components. It denotes relative to land area under sole crop required to produce the same yield as obtained under a mixed or an intercropping system at the same level of management. It is the ratio of land required by the pure crop to produce the same yield as intercrop. The LER was worked out by using the following formula given by Willey (1979).

$$LER = La + Lb = (Ya/Sa + Yb/Sb)$$

Where, LER = Yield of intercrop over yield of pure crop; La and Lb = LER's for the crops a and b; Ya, Yb is the yield of a and b crop grown as an intercrop; Sa, Sb is the yield of a and b crop grown as a sole crop.

When LER >1 intercropping is advantageous, the reverse means the 2 crops are mutually antagonistic.

Rice equivalent yield was also worked out. Normally, crop equivalent yield refers to the yields of different intercrops/crops are converted into the equivalent yield of any one crop based on the price of the produce. Efforts have also been made to convert the yields of different crops into an equivalent yield of the main crop such as rice (Verma and Modgal, 1983).

The rice equivalent yield of an intercropping system was calculated by taking into account the grain yield of component crops and the prevailing market price of both rice and intercrops as follows:

$$\text{REY (Kg ha}^{-1}\text{)} = \begin{array}{c}\text{Yield of rice in}\\ \text{intercropping}\\ \text{system (Kg ha}^{-1}\text{)}\end{array} + \left[\begin{array}{c}\text{Yield of}\\ \text{Intercrop}\\ \text{(Kg ha}^{-1}\text{)}\end{array} \times \frac{\text{Market price of intercrop (Rs kg}^{-1}\text{)}}{\text{Market price of rice (Rs kg}^{-1}\text{)}} \right]$$

The production efficiency was also calculated based on the rice equivalent yield and the duration of the cropping system and expressed as kg day^{-1}

$$\text{PE (kg day}^{-1}\text{)} = \frac{\text{Rice equivalent yield}}{\text{Duration of cropping system}}$$

Data analysis

To compare the performance of sole rice treatments with the rest of intercrops, an RCBD with 5 treatments was used. Weed density was expressed on a square metre basis and was square root transformed before the Analysis of Variance (ANOVA) as described by Cochran and Cox (1957). Weed biomass was expressed in g m^{-2} and weed density was expressed in numbers m^{-2} before ANOVA. Rice grain, straw and leafy vegetable yield were expressed in ha^{-1} before the ANOVA. Means were separated using Least Significant Difference (LSD) at P<0.05. The productivity of intercropping was assessed by calculating the REY, LER, PE and net monetary return from component crop yields

3. Results

Effect of the rice-leafy vegetable intercropping system on weed density

Total weed density in aerobic rice was significantly influenced by different leafy vegetables intercropping systems at 30, 60, 90 days after sowing (DAS) and at harvest (Table 1). Total weed density at 30 DAS was significantly lower in rice intercropped with palak and sole palak (20.00 and 25.33; 25.08 and 30.88 no. m^{-2} during 2017 and 2018, respectively) as

Table 1 - Total weeds density (no./m^2) in rice as influenced by different intercropping systems during 2017 and 2018

Weed management practices	30 DAS		60 DAS		90 DAS		At harvest	
	2017	2018	2017	2018	2017	2018	2017	2018
T_1: Rice+Amaranth	5.34(29.33)	5.89(34.25)	7.42 (54.67)	7.73(59.23)	8.57(73.33)	8.93(79.25)	8.51(72.00)	8.76(76.30)
T_2: Rice+Coriander	6.75(45.33)	7.16(50.70)	8.81(78.67)	9.14(82.98)	9.95(98.67)	10.24(104.28)	9.89(97.33)	10.04(100.28)
T_3: Rice+Palak	4.32(20.00)	5.06(25.08)	5.71 (34.67)	6.52(42.05)	7.33(53.33)	7.73(59.33)	7.24(52.00)	7.56(56.70)
T_4: Rice+Methi	6.23(38.67)	6.67(43.98)	8.19(66.67)	8.51(72.00)	9.11(82.67)	9.32(86.45)	8.97(80.00)	9.28(85.70)
T_5: Sole Rice	7.77(61.33)	8.19(66.55)	9.74(96.00)	10.24(104)	10.35(106.67)	10.59(111.68)	10.28(105.33)	10.55(110.80)
T_6: Sole amaranth	6.04(36.00)	6.55(42.43)	-	-	-	-	-	-
T_7: Sole Coriander	7.05(49.33)	7.38(53.90)	-	-	-	-	-	-
T_8: Sole Palak	5.08(25.33)	5.60(30.88)	-	-	-	-	-	-
T_9: Sole Methi	6.56(42.67)	7.00(48.50)	-	-	-	-	-	-
S.Em.±	0.46	0.027	0.56	0.026	0.19	0.007	0.16	0.014
CD (P=0.05)	1.36	0.08	1.76	0.08	0.61	0.021	0.51	0.043

Values in parentheses are original values; data analysed using transformation -√x + 0.5.
DAS= Days after sowing.

compared to the sole rice crop (61.33 and 66.55 no. m^{-2} during 2017 and 2018, respectively).

Among different intercropping practices, intercropping of rice and leafy vegetable palak recorded significantly lower density of total weeds at 60 DAS (34.67 and 42.05 no. m^{-2} during 2017 and 2018, respectively). It was followed by intercropping of rice and leafy vegetable amaranths: at 60 DAS (54.67 and 59.23 no. m^{-2}, respectively). However, the sole rice registered a bit higher number of total weeds (96.00 and 104 no. m^{-2}, respectively). The similar trend was noticed at the further crop growth stage of aerobic rice at 90 days after sowing and at harvest.

Effect of the rice-leafy vegetable intercropping system on weed dry weight

The weed dry weight is the useful parameter to assess the extent of weed competition with the crop plants. The total weeds were differed significantly at different growth stages of aerobic rice due to different intercropping practices. The 2 years pooled data are here under depicted in figure 1.

Total weed dry weight in aerobic rice was significantly lower in rice-palak leafy vegetables intercropping systems at 30 DAS, 60, 90 and at harvest (0.25, 115.34, 151.20 and 148.04 g m^{-2}, respectively) as compared to the sole rice crop (1.56, 204.07, 302.09 and 279.08 g m^{-2}, respectively). However, the latter

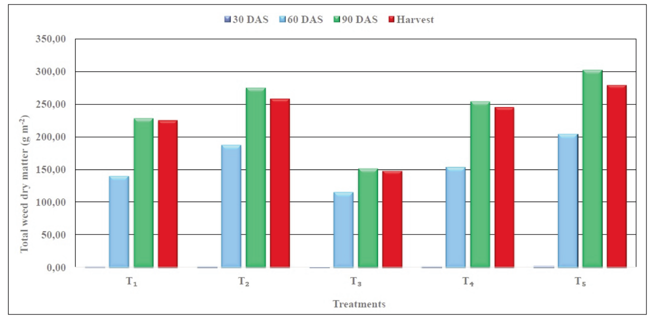

Fig. 1 - Total weed dry weight at different growth stages as influenced by different intercropping systems, pooled data 2017 and 2018. T1: Rice+Amaranth, T2: Rice+Coriander, T3: Rice+Palak, T4: Rice+Methi, T5: Sole Rice.

was followed by intercropping of rice and leafy vegetable amaranths (0.47, 140.15, 228.05 and 225.15 g m^{-2}, respectively).

Effect of the rice-leafy vegetable intercropping system on weed smothering efficiency

Weed smothering efficiency is a measure of the effect of intercropping on the suppression of weeds in comparison to sole crop stand. The data pertaining to the weed smothering efficiency are presented in Table 2.

In the present experiment, the higher weed smothering efficiency was found in intercropping of

Table 2 - Rice grain, straw and leaf vegetable yield, rice equivalent yield (REY), land equivalent ratio (LER), production efficiency (PE), net monetary income and weed smothering efficiency (WSE) in rice as influenced by different intercropping systems, during 2017 and 2018

Practices	Grain yield (kg ha-1)		Straw yield (kg ha-1)		Vegetable yield (kg ha-1)		REY (kg day^{-1})		LER		PE (kg day-1)		Net income (₹ &US$ha-1)		WSE (%)	
	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018	2017	2018
T_1	6730	5755	8382	8167	14248	13811	11479	10358	1.88	1.82	76.53	69.05	76010₹ 1096 US$	74749₹ 1078 US$	20.07	18.60
T_2	6018	5443	8030	7841	12057	11226	10037	9185	1.82	1.79	66.91	61.24	59357₹ 856 US$	56543₹ 815 US$	8.15	6.88
T_3	7951	7351	9794	9580	25810	25207	16554	15753	2.12	2.15	110.36	105.02	158025₹ 2278 US$	154515₹ 2228 US$	48.09	45.86
T_4	6444	5644	8196	8010	14133	12056	11155	9663	1.87	1.88	74.37	64.42	72095₹ 1039 US$	70098₹ 1011 US$	12.54	11.64
T_5	5978	5403	7382	7174	-	-	-	-	-	-	-	-	-	-	-	-
T_6	-	-	-	-	19010	18407	-	-	-	-	-	-	-	-	-	-
T_7	-	-	-	-	15086	14482	-	-	-	-	-	-	-	-	-	-
T_8	-	-	-	-	32705	32105	-	-	-	-	-	-	-	-	-	-
T_9	-	-	-	-	18743	15893	-	-	-	-	-	-	-	-	-	-
S.Em.±	92.32	183.89	260.38	259.15	1555	1427	684	713	0.09	0.06	4.08	4.19	NA	NA	NA	NA
CD @5%	296.99	572.91	811.20	807.36	4604	4191	2252	2313	0.28	0.21	12.7	13.06	NA	NA	NA	NA

T1: Rice+Amaranth, T2: Rice+Coriander, T3: Rice+Palak, T4: Rice+Methi, T5: Sole Rice, T6: Sole amaranth, T7: Sole Coriander, T8: Sole crop Palak, T9: Sole crop Methi ; NA=Not analysed; (indian rupees: ₹ converted into US$ at the rate of 69.35₹ against 1 US$ on 29th March 2019).

rice and leafy vegetable palak (48.09 and 45.86%, 2017 and 2018, respectively) followed by intercropping of rice and leafy amaranthus (20.07 and 18.60%, 2017 and 2018, respectively).

Effect of the rice-leafy vegetable intercropping system on nutrient uptake by crops and weeds

The weeds withdraw the nutrients that would have normally available to the crop. As the nutrient uptake is increased by weeds on account of higher weed population, the harmful effect could be expected on the crop. When the weed growth is effectively managed through integrated weed management, a decline in nutrient uptake by weeds is a natural consequence. Uptake of major soil nutrients by weeds and crops indicated that the rate of increase in the uptake was proportional to the dry matter production.

The 2 years pooled data on uptake of nitrogen, phosphorus and potassium by rice, leafy vegetables at harvest and weeds at 60 DAS as influenced by different intercropping practices are given in figures 2 and 3. The total nitrogen (153.78 kg ha^{-1}), phosphorous (45.27 kg ha^{-1}) and potassium (152.22 kg ha^{-1}) uptake by rice crop at harvest were significantly higher in intercropping of rice with leafy vegetable palak as compared to sole rice (109.90, 29.49 and 109.25 kg NPK ha^{-1}, respectively). Similar trend was seen with uptake by leafy vegetable crop (Fig. 3) wherein leafy vegetable palak intercropped with rice significantly recorded higher amount of the total nitrogen (101.09 kg ha^{-1}), phosphorous (14.18 kg ha^{-1}) and potassium (38.97 kg ha^{-1}) followed by leafy vegetable amaranthus intercropped with rice (77.08, 8.98 and 28.81 kg NPK ha^{-1}, respectively).

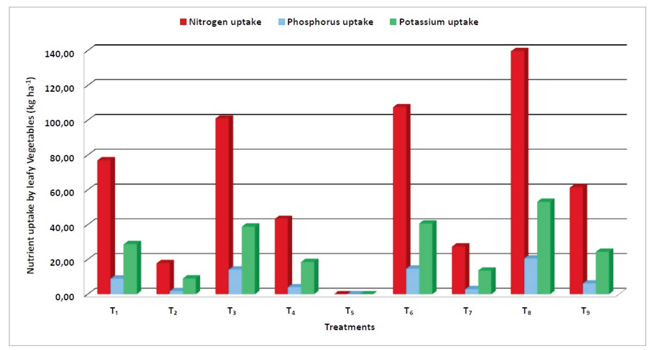

Fig. 3 - Nutrient uptake by leafy vegetable crops at harvest as influenced by different intercropping systems, pooled data 2017 and 2018. T1: Rice+Amaranth, T2: Rice+Coriander, T3: Rice+Palak, T4: Rice+Methi, T5: Sole Rice, T6: Sole amaranth, T7: Sole Coriander, T8: Sole crop Palak, T9: Sole crop Methi.

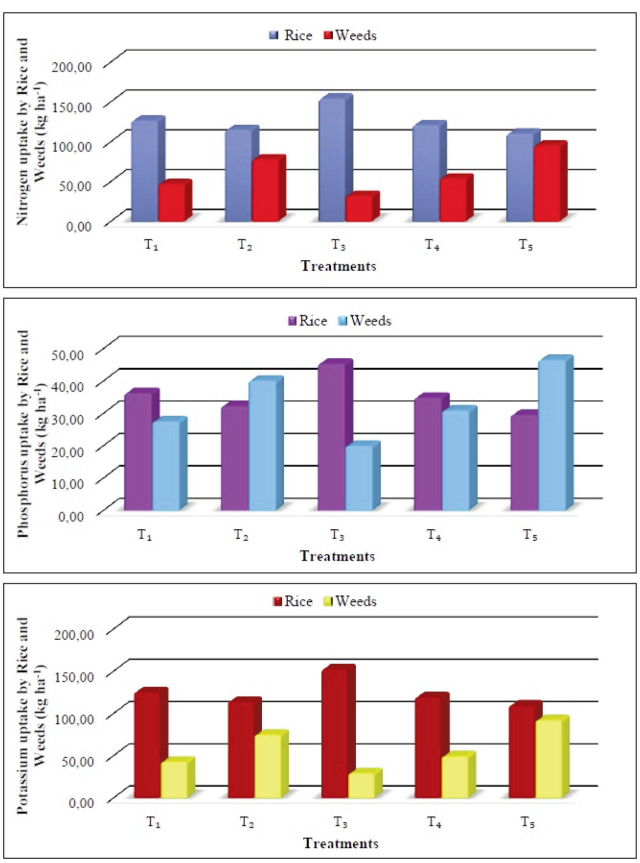

Fig. 2 - Nutrient uptake by rice crop at harvest and weed at 60 DAS as influenced by different intercropping systems. T1: Rice+Amaranth, T2: Rice+Coriander, T3: Rice+Palak, T4: Rice+Methi, T5: Sole Rice.

At 60 days of crop growth (Fig. 2), the nitrogen, phosphorous and potassium uptake by weeds were significantly influenced by different intercropping practices. Significantly lower nitrogen (31.88 kg ha^{-1}), phosphorus (19.90 kg ha^{-1}) and potassium (28.92 kg ha^{-1}) uptake were recorded with the intercropping of rice+leafy vegetable palak. It was followed by intercropping of rice with leafy vegetable amaranth: nitrogen (46.72 kg ha^{-1}), phosphorus (27.39 kg ha^{-1}) and potassium (42.68 kg ha^{-1}) uptake as compared to sole rice (94.93, 46.48 and 91.83 kg NPK ha^{-1}, respectively).

Effect of the rice-leafy vegetable intercropping system on rice and vegetable yield and efficiencies

The rice grain yield, straw yield, leafy vegetable yield, Rice Equivalent Yield (REY), Land Equivalent Ratio (LER), Production Efficiency (PE) and net monetary income differed significantly due to different intercropping practices. The data are accessible in Table 2.

Significantly higher grain yield, straw yield, vegetable leaf yield (7951, 9794, 25810 kg ha^{-1} and 7351, 9580, 25207 kg ha^{-1} for 2017 and 2018, respectively) were recorded in intercropping of rice with leafy vegetable palak as compared to grain and straw yield of sole rice (5978, 7382 and 5403, 7174 kg ha^{-1} for 2017 and 2018, respectively). It was followed by intercropping of rice with leafy vegetable amaranth (6730, 8382, 14248 kg ha^{-1} and 5755, 8167, 13811kg ha^{-1} for 2017 and 2018, respectively).

Rice equivalent yield is the best tool to determine the overall productivity potential of an intercropping system. The data presented in Table 2 reflected visible variation in REY among the intercropping systems showing the highest REY (16554 and 15753 kg ha^{-1} in 2017 and 2018, respectively) for intercropping of rice with leafy vegetable palak followed by intercropping of rice with leafy vegetable amaranthus (11479 and 10358 kg ha^{-1}) which was on par with intercropping of rice with leafy vegetable methi (fenugreek) (11155 and 9663 kg ha^{-1}).

The data on Land Equivalent Ratio of different intercropping systems indicated that LER values were greater than one in all the intercropping practices and the range of yield advantage over sole cropping of rice was between 79 and 115 per cent with the highest in case of intercropping of rice with leafy vegetable palak (115 per cent) followed by intercropping of rice with leafy vegetable methi (88 per cent) compared to monocropping of rice.

Significantly higher Production Efficiency was recorded in intercropping of rice with leafy vegetable palak (110.36 and 105.02 kg day^{-1} in 2017 and 2018, respectively) and was closely followed by intercropping of rice with leafy vegetable amaranthus (76.53 and 69.05 kg day^{-1}) in both years.

Net monetary income (indian rupees: ₹ converted into US$ at the rate of 69.35₹ against 1 US$ on 29th March 2019) was higher in intercropping of rice with leafy vegetable palak (₹ 158025 equivalent to **US$** 2278) ha^{-1}; ₹154515 equivalent to US$ 2228) ha^{-1} for 2017 and 2018, respectively) followed by intercropping of rice with leafy vegetable amaranthus (₹ 76010 equivalent to US$1096); ₹ 74749 equivalent to US$ 1078) ha^{-1} for 2017 and 2018, respectively).

4. Discussion and Conclusions

The weed population and total dry weight of weeds differed significantly due to different intercropping systems (Table 1, Fig. 1). The decline in weed density and lower weed dry matter accumulation in rice + palak intercropping systems may be attributed to shading effect and competition stress generated by the canopy of leafy vegetable in a unit area having smothering effect on associated weeds, thus preventing the weeds to attain the full growth (Banik and Ravi, 2013). The intercropping system suppressed the weed growth due to their spreading canopy coverage. The increased populations per unit area and crop competition in intercropping were also the possible reason for effective weed control (Jha and Dinesh, 1982; Ibni *et al.* 2005; Abdul *et al.* 2009; Mian *et al.* 2011).

Higher weed smothering efficiency (Table 2) in rice + palak intercropping systems resulted from less space available for the growth of weeds due to quick coverage of ground and more shading effect which led to the lower total weed population and its dry weight. Similar findings were also reported by Musthafa and Potty (2001); Vyas and Kushwah (2008) and Mian *et al.* (2011).

The higher rice grain yield could be attributed to better yield attributing parameters namely higher no. of productive tillers hill^{-1}, higher panicle length, higher panicle weight hill^{-1}, higher total no. grain panicle^{-1}, higher 1000 grain weight and higher harvest index as compared to sole rice. The above increment in yield was attributed to increased growth attributes such as higher total dry matter production and distribution in various parts of the plant and higher leaf area as well. In addition to this, the higher canopy coverage by palak has resulted in a reduction in total weed population which turned the equilibrium in favor of crop for the use of the available resources. Similarly, in the intercropping system, significantly higher fresh leafy vegetable yield (25508 kg ha^{-1}) was recorded in intercropping of rice with leafy vegetable palak followed by intercropping of rice with leafy amaranthus (14029 kg ha^{-1}, respectively). However, the sole leafy vegetable palak registered higher yield (32405 kg ha^{-1}) followed by sole leafy amaranthus (18708 kg ha^{-1}). These findings are in the similar trend with Ibni *et al.* (2005); Ahmed *et al.* (2006); Mian *et al.* (2010).

The higher nutrients uptake by rice crop and leafy vegetables in intercropping of rice with leafy vegetable palak might be attributed to minimum crop-weed competition as a result of higher weed smothering efficiency, gave the better control of weeds from initial stages which led to lower weed population and their dry weight, this helped the crop to grow in weed-free environment and absorb more nutrients from the soil. Hence, resulted in better growth and development of leafy vegetable and rice crops leading to better nutrient uptake. A similar report was also reported by Abdul *et al.* (2009) and

Mian *et al.* (2010).

The lower nutrient uptake by weeds in intercropping of rice with leafy vegetable palak was mainly due to better control of weeds as a result of lower weed competition leading to lower weed dry matter production as also noticed by Ibni *et al.* (2005); Abdul *et al.* (2009) and Mian *et al.* (2010).

The percentage increase over sole cropping of rice as a result of different intercropping systems, however, varied from 46.74 to 76.83 % clearly indicating substantial yield advantage of intercropping. The variation in REY under different cropping systems was ascribed to their variable utilization of soil and agro-resources. Higher yield benefit in terms of REY of intercropping over monocropping of rice has also been revealed by Abdul *et al.* (2009), Mian *et al.* (2011), Nagwa *et al.* (2014), Rayhan *et al*. (2014), and Gurpreet Singh *et al*. (2018).

The data on LER of different intercropping systems indicated that LER values were greater than one in all the intercropping treatments and the range of yield advantage over sole cropping of rice was between 79 and 115 per cent with the highest in case of intercropping of rice with leafy vegetable palak (115 per cent) followed by intercropping of rice with leafy vegetable amaranthus (85 per cent) compared to monocropping of rice was attributed to better utilization of natural resources (land, CO_2 and light). Higher LER in intercropping compared to monocropping of rice was also reported by Abdul *et al.* (2009), Mian *et al.* (2011), Nagwa *et al.* (2014), Udhaya and Kuzhanthaivel (2015) (Table 2).

Significantly higher PE was recorded in intercropping of rice with leafy vegetable palak (107.69 kg day^{-1}) and was closely followed by intercropping of rice with leafy vegetable amaranthus (72.79 kg day^{-1}). The result indicated that the intercrops remained in the field for a shorter time (30 DAS) and yields were also high leading to higher production per day. The similar tendency was noted by Ibni *et al.* (2005); Nazrul and Shaheb (2011) and Rayhan *et al*. (2014) (Table 2).

The higher net income increases in intercropping of rice with leafy vegetable palak was mainly due to the higher rice grain, rice straw yield, rice equivalent and higher leafy vegetable yield which in turn increased gross and net returns. These results are in agreement with the findings of Ibni *et al.* (2005); Abdul *et al.* (2009); Mian *et al.* (2010).

In this experiment, rice crop intercropped with palak as a leafy vegetable was found to be the most efficient practice in smothering the weeds by reducing the weed density and dry weight which significantly increased growth, yield and profitability of aerobic rice compared to the rest of intercrops and sole rice. Since all the leafy vegetable seeds were broadcasted, the use of smother leafy vegetable crops as an intercrop in definite row proportion in aerobic rice is encouraged.

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