Madras Agric. J., 2021; https://doi.org/10.29321/MAJ.10.000510

RESEARCH ARTICLE

Evaluation of Rice-Based Cropping Sequences for Water Scarce Conditions of Parambikulam Aliyar Command Area of Tamil Nadu

Sudhalakshmi C*[1], Rani S[2] and Geethalakshmi V[3]
[1]Soil Science and Agricultural Chemistry, Coconut Research Station, Aliyarnagar- 642 101
[2]Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore-641 003
[3]Tamil Nadu Agricultural University, Coimbatore-641 003

Received : 15th, May 2021
Revised : 20th, May 2021
Revised : 29th, May 2021
Accepted : 2nd, June 2021

ABSTRACT

Field experiments were conducted at Coconut Research Station, Aliyarnagar during 2016 – 2019 to assess the performance of rice-based cropping sequences for water-scarce conditions of the Parambikulam Aliyar Project Command area of Tamil Nadu. Five cropping sequences *viz.,* rice–sesame (T_1), rice–groundnut (T_2), rice– sunflower (T_3), rice–castor (T_4) and rice–black gram (T_5) were experimented adopting Randomized Block Design with each sequence replicated four times. Results revealed that compared to the other non-legume sequences experimented, the contents of $KMnO_4$-N and organic carbon in the post harvest soil, productivity of rice and economic efficiency were higher in rice–black gram followed by rice–groundnut sequence. Rice–castor sequence recorded the highest land utilization efficiency of 76.7 % and was the lowest in rice–black gram sequence (53.4 %). Rice equivalent yield was the highest on sequential cropping with sunflower (5755 kg ha^{-1}) followed by groundnut (5028 kg ha^{-1}). Production efficiency was the highest in rice– groundnut (47.5 kg ha^{-1} day^{-1}) followed by rice–castor (42.5 kg ha^{-1} day^{-1}) systems. Net returns and benefit-cost ratio were higher in rice–sunflower and rice–black gram sequences followed by rice–groundnut and was the lowest in rice–sesame sequence. In terms of soil fertility, system productivity and economic returns, rice–sunflower, rice–black gram and rice–groundnut systems are highly remunerative for water-scarce conditions of Parambikulam Aliyar Command Area of Tamil Nadu.

Key words : *Rice; Cropping Sequence; Rice Equivalent Yield; Net Returns; Production Efficiency; Economic Efficiency*

INTRODUCTION

Rice and wheat are the two important cereals that witnessed India to a dramatic switch over of food grain export in the 1990s from mere self-sufficiency in the 1980s. Rice has been the companion of humankind for more than 8000 years providing staple food to 2.5 billion people which may escalate to 4.6 billion by 2050 (Lampe, 1995). In India, its acreage spreads over 44.5 million hectares constituting 34 % of the area under food crops and 42 % under cereals, with a total production of 117.47 million tonnes and productivity of 2639 kg ha^{-1}. In Tamil Nadu, this domesticated crop is cultivated over 17.22 lakh hectares with a production of 64.54 lakh metric tonnes and productivity of 3748 kg ha^{-1} (GoTN, 2019). Rice production in the tropics is sensitive to climatic factors like temperature, rainfall, and solar radiation affecting the crop in various ways during different stages of its growth (Yoshida, 1978). The adverse impacts of climate change on rice production systems have been increasing over recent years (Matsushima *et al*., 1966).

Rice is a profligate user of water, and more than five tonnes of water is required to grow one kilogram of rice. The water use efficiency of rice is only 3.7 kg/ha/mm (Subbian *et al*., 2000), which is far less compared to the other predominant field crops known. Coimbatore is one of the agriculturally important districts of Tamil Nadu in which the majority of the agricultural lands are benefitted from the Parambikulam Aliyar Project (PAP), which is a major interstate multipurpose irrigation project. Rice, coconut, groundnut and vegetables are the principal crops of the command area with a total ayacut of 1.74 lakh hectares. Rice–rice-green manures is the predominant cropping system practised for ages by the farmers of the Anaimalai belt of PAP command because of the unprecedented irrigation water from the Aliyar reservoir. However, during 2016 and the years followed, the mean annual rainfall of the

*Corresponding author's e-mail: soilsudha@yahoo.co.in

region was 59.4 % less than the average annual rainfall of 808 mm, which posed a significant impediment for rice cultivation. Several thousand acres of agricultural lands were kept barren for want of irrigation water. In the event of monsoon failure, Aliyar reservoir can support only one rice crop *(Kharif)* per year and the rice growers incur huge losses by sacrificing the second *Rabi* rice crop. Besides water scarcity, continuous rice cropping also resulted in other problems like a relatively low response of nitrogen (N) fertilizers and slow mineralization rates as stated by Cassman *et al.* (1995) and Olk and Cassman (1995). Occurrence of second-generation problems such as over-mining of soil nutrients, the decline in factor productivity, reduction in profitability, lowering of ground-water table and build-up of pests including weeds, diseases and insects has been reported in continuous rice-rice cropping system (Ray *et al*., 2009) signifying the importance of crop diversification. Due to the introduction of short and medium duration rice varieties, multiple cropping and the diversification of rice-based cropping system is possible with the inclusion of pulses, oilseeds and vegetables and this has been found more beneficial, providing enhanced productivity of the system and improved soil fertility status than cereal–cereal sequence (Kumpawat, 2001 and Sravan *et al.,* 2015), in alleviating the poverty, employment generation, ensuring balanced food supply, and improving productivity and sustainability of the cropping systems (Sravan and Murthy, 2018).

Sahrawat (2004) reported the importance of grain legumes in rice–based rotations to enhance the decomposition of accumulated organic matter as against the slow decomposition rate in continuously waterlogged rice soils. Evidence accumulate stating that inclusion of pulses, oilseeds and vegetables in the system is more beneficial than cereals after cereals, and such inclusion in a sequence changes the economics of the crop sequences (Patra *et al*., 1989; Gangwar *et al*., 2004; Ghosh *et al*., 2007 and Jat *et al*., 2012). The introduction of legumes and oilseeds can provide a sustainable production base to the continued rice mono-cropped system, which otherwise leads to a decline in total factor productivity. Hence, research has been envisaged on identifying low water requiring alternative crops that are highly productive, resource efficient, remunerative and sustainable, to fit into rice-based cropping system for the PAP command area of Tamil Nadu, based on soil fertility, system productivity and economic returns.

MATERIAL AND METHODS

Field experiments were conducted during 2016-2019 in Field Number A3 of Coconut Research Station, Aliyarnagar (10^0 29’ 449 N; 076^o 58’ 775 E) to elicit the impact of rice-based cropping systems on soil fertility, system productivity and on economic returns. The soil is sandy loam in texture, classified taxonomically as *Typic Ustropept.* The bulk density of the soil is 1.35 Mgm^{-3}, particle density of 2.46 Mg m^{-3} and porosity is 45.2%. The pH of the experimental soil is 7.96 with an electrical conductivity of 0.33 dSm^{-1}. The major nutrients such as $KMnO_4$-N was 242 kg ha^{-1}, Olsen P of 14.4 kg ha^{-1}, NNH_4OAc – K of 246 kg ha^{-1} indicating the low and medium status of the nutrients respectively. The organic carbon content of the soil was medium (5.2 g kg^{-1}). Experiment was conducted in a Randomized Block Design with each treatment replicated four times. Five rice-based cropping systems *viz.,* rice–sesame (T_1), rice–groundnut (T_2), rice–sunflower (T_3), rice-castor (T_4) and rice–black gram (T_5) were evaluated for their production potential, soil fertility and economics. After the first crop of rice, without disturbing the plots, the field was prepared using a power tiller to optimum tilth and the sequential crops were raised adopting the crop management practices furnished in Table 1. The *Kharif* crop of rice was sown during the last week of June and harvested during October and the sequential crops were sown during October. During *Kharif*, the crop was irrigated to maintain a saturated moisture regime whilst *Rabi* crops were irrigated only at critical crop growth stages. Irrigation water was quantified through Parshall Flume placed in the field.

Table 1. Agronomic package of practices followed for crops of the sequence

Particulars	Rice	Groundnut	Sunflower	Castor	Sesame	Black gram
Variety	CO50	CO7	CO2 hybrid	YRCH 1	TMV 7	ADT 5
Duration (days)	130-135	100-105	90-95	150-160	80-85	65-70
Seed Rate (kg ha^{-1})	40	125	4.0	5.0	5.0	20.0
Land Configuration	Flat Bed	Flat Bed	Ridges and Furrows	Ridges and Furrows	Flat Bed	Flat Bed
Spacing	(20 x 10) cm	(30 x 10) cm	(60 x 30) cm	(150 x 120) cm	(30 x 30) cm	(30 x 10) cm
Planting method	Transplanting	Dibbling	Dibbling	Dibbling	Sand mix	Broadcasting
Fertilizer (NPK)/ha	150 – 50 - 50	25-50-75	60 – 90- 60	90 – 45-45	35-23-23	25-50-25
Special management practices	-	Gypsum @ 200 kg ha^{-1} on 45 DAS	Borax spray @ 0.2 % at capitulum formation stage	-	$MnSO_4$ @5 kg ha^{-1}	2 % DAP spray on 30 and 45 DAS

To elicit the differential effect of cropping sequences on soil fertility, soil samples were collected at the end of the first crop and sequential crops. Analyses *viz.,* pH, electrical conductivity (Jackson, 1973), $KMnO_4$- N (Subbiah and Asija, 1956), Olsen P (Olsen *et al.,* 1954), NNH_4OAc – K (Stanford and English, 1949) and organic carbon content (Walkley and Black, 1934) were performed adopting the standard procedures. Economics of the cropping sequences were worked out on the basis of the market price of the product and other agro-inputs. Productivity of the cropping sequences was assessed based on rice-equivalent yield. Water use efficiency was computed as the ratio of yield obtained per unit of available water (Sinclar *et al.,* 1984). Rice equivalent yield (kg ha^{-1}) was calculated employing the following formula

$$\text{Rice Equivalent yield} = \frac{\text{Yield of the sequential crop (kg ha}^{-1}\text{) x Price of the crop (Rs. kg}^{-1}\text{)}}{\text{Price of rice (Rs. kg}^{-1}\text{)}}$$

Land use efficiency (LUE) was obtained by dividing the total duration of crops in an individual cropping system by 365 days (Chuang, 1973). Production efficiency values were obtained by dividing total production in sequence by the total duration of a cropping sequence (Tomar and Tiwari, 1990). Net returns were worked out as the difference between gross returns and the cost of cultivation. Economic efficiency (Perin *et al.,* 1979) in terms of Rs. ha^{-1} day^{-1} was worked out by dividing the net returns of a cropping sequence by the total duration of the cropping sequence in a year. Pooled analysis was performed from the data accrued across three years and subjected to statistical scrutiny employing Gomez and Gomez (1984) and the results are discussed in detail based on the critical differences obtained.

RESULTS AND DISCUSSION

Weather variables

The weather variables recorded in the Agro Meteorological Observatory of Coconut Research Station, Aliyarnagar for the period 2014 – 2020 is presented in Table 2. The minimum temperature ranged from 21.5°C to 27.5°C and the maximum temperature from 35.3°C to 38.0°C in the said period.

Table 2. Weather variables recorded at Coconut Research Station, Aliyarnagar

Year	Max. Temp. (°C)	Min. Temp (°C)	Rainfall (mm)	Relative Humidity (%)	Evaporation (mm)	Wind Velocity (kmph)
2014	36.7	25.0	1054.9 (83)	90.8	5.9	3.1
2015	35.3	22.3	1073.7 (76)	92.4	6.5	2.5
2016	38.0	23.9	480.4 (31)	90.0	8.0	4.0
2017	36.8	24.2	748.1 (50)	93.4	5.6	2.9
2018	36.8	23.1	1085.5 (73)	96.8	4.8	2.7
2019	38.0	27.5	896.01 (67)	97.2	9.0	4.4
2020	37.5	21.5	684.9 (57)	94.2	4.8	6.2

Figures in parentheses represent the number of rainy days

Rainfall received during 2016 was 40.5% lesser than the mean annual rainfall of the region and the water levels in the reservoirs dropped down drastically forcing the farmers to abandon rice cultivation. The scenario reversed only during 2018 and thereafter again there was a dent in rainfall during 2020.

Table 3. Initial and post-harvest soil fertility status of paddy–oilseeds cropping sequence experiment

Cropping System	pH		EC (dSm^{-1})		$KMnO_4$-N		Olsen P		NNH_4OAc- K		Organic carbon (g kg^{-1})	
					(kg ha^{-1})							
	2016	2019	2016	2019	2016	2019	2016	2019	2016	2019	2016	2019
T_1: Rice-Sesame	7.96	8.04	0.33	0.41	248	196	14.6	14.0	246	214	4.6	4.6
T_2: Rice-Groundnut	8.02	8.01	0.24	0.37	234	278	14.1	14.8	220	235	5.4	5.7
T_3: Rice-Sunflower	7.87	7.98	0.24	0.31	247	254	14.4	14.2	216	228	4.6	4.6
T_4: Rice-Castor	8.04	8.06	0.20	0.32	238	232	14.4	14.0	237	220	5.4	4.6
T_5: Rice–Black gram	7.98	7.87	0.31	0.34	247	282	14.6	15.1	228	248	5.4	5.7
Mean	7.96	7.99	0.33	0.35	242.8	253	14.4	14.4	246	229	5.1	5.0
S. Ed.	0.554	0.618	0.022	0.02	18.6	19.5	1.108	1.12	17.9	17.4	0.39	0.39
CD (P = 0.05)	NS	NS	NS	NS	NS	45.6	NS	NS	NS	NS	NS	0.9

Soil Fertility Status

The initial and post-harvest soil fertility status for the period 2016 – 2019 is presented in Table 3. Compared to the initial soil fertility status during 2016, soil reaction and electrical conductivity registered a mild increase in the post-harvest soil during 2019; however no significant variation was observed between the cropping sequences adopted. It is a natural corollary that the pH of the soil under submergence converges to neutrality (Kar *et al*., 1977 and Ponnamperuma, 1978) and hence sequential crops did not impact their influence on the pH of the post-harvest soil. Electrical conductivity did not register significant variation among the cropping sequences adopted.

Table 4. Growth attributes of rice in rice-based cropping sequence at harvest stage (2016 -19)

Cropping system	Plant height (cm)	Number of leaves per plant	Root length (cm)	Dry matter Production (kg ha^{-1})
T_1: Rice-Sesame	92.20	43	15.85	10150
T_2: Rice-Groundnut	89.75	41	15.60	10200
T_3: Rice-Sunflower	94.12	46	14.33	10100
T_4: Rice-Castor	87.83	42	15.75	10100
T_5: Rice–Black gram	86.32	45	15.90	10300
Mean	90.04	43	15.49	10170
S.Ed.	6.79	3.17	1.17	760
CD (P = 0.05)	NS	NS	NS	NS

The content of $KMnO_4$-N was higher in the rice–black gram sequence followed by rice–groundnut and rice–sunflower sequences and was the lowest in rice–sesame sequence. The results are in proximity to the findings of Tamilezhai *et al*., (2018). The residual nitrogen benefits of legumes have been well documented by several workers (Ahmad *et al.,* 2001; Wasim *et al.,* 2015 and Kakraliya *et al.,* 2018). In an experiment conducted to assess the residual nitrogen benefits to rice in farmers' fields of North East Thailand, it was found that groundnut fixed 72-77 % of its nitrogen amounting to 150 – 200 kg N ha^{-1} in 106 – 119 days (Toomson *et al*., 1995).

Table 5. Growth at harvest, yield attributes and yield of sequential crops in rice-based cropping sequence (2016 – 19)

Cropping system	Plant population per m^2	Plant height (cm)	Number of pods per plant	100 seed weight (g)	Seed / Kernel yield (kg /ha)	Haulm / Stalk yield (kg /ha)
T_1: Rice-Sesame	10	153.4	56	2.30	870	2420
T_2: Rice-Groundnut	30	25.0	23	30.5	1257	2828
T_3: Rice-Sunflower	05	160.9	01	5.0	2150	2756
T_4: Rice-Castor	-	82.9	42	26.0	1465	2986
T_5: Rice–Black gram	30	26.2	23	3.6	700	2440

In a trial on sequential cropping, nitrogen fixation by groundnut was significant and the residual N effect was higher on the succeeding rice crop (Senaratne and Ratnasinghe, 1995). Although the availability of phosphorus and potassium did not show any statistical superiority among the treatments in the post-harvest soil, there was mining of potassium in the soil of rice-sesame sequence. As sesame is one of the heavy feeders of nutrients (Adisu *et al*., 2020), there is a depression in the soil fertility status of the post-harvest soil compared to the other sequences experimented with. Organic carbon content in the post-harvest soil was higher in rice-black gram, rice-groundnut and rice-castor cropping sequences owing to the recycling of stubbles in the above systems.

Growth and Yield attributes

Plant height of rice at harvest ranged from 86.32 cm to 94.12 cm, the number of leaves per plant from 41 to 46, root length from 14.33 to 15.90 cm and dry matter production from 10100 to 10300 kg ha^{-1} (Table 4). Although statistical parlance was observed among the cropping sequences on the

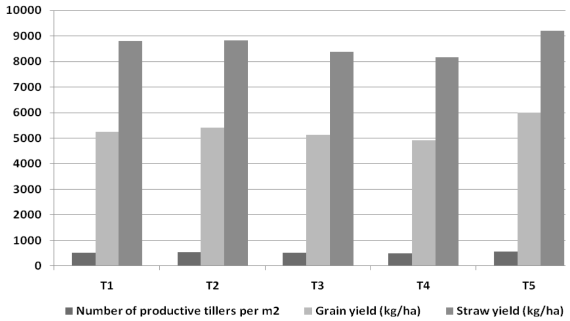

Figure 1. Yield attributes and yield of rice in rice-based cropping sequences (2016 – 19)

above parameters, the inclusion of black gram in the system resulted in increased dry matter production of rice crops. Diverse cropping sequences adopted did not bring noteworthy differences in a number of productive tillers per plant. However, numerically higher grain yield were recorded in rice-black gram system followed by rice - groundnut system (Figure 1). An array of evidence states that the inclusion of legumes in rice based cropping system increases the productivity of rice (Ahmad *et al.,* 2001; Hegde, 2003; Kakraliya *et al.,* 2018, Nath *et al.,* 2019 and Ghosh *et al.,* 2019). Introduction of a legume in rice-based cropping system has several advantages like biological nitrogen fixation which include nutrient recycling from deeper layers, minimizing soil compaction, increasing soil organic matter and breaking pest cycles (Sanford and Hairstron, 1984; Wani *et al*., 1995). Thus in the present study, rice yield was higher in rice-black gram and rice-groundnut systems compared to the other non-legume sequences experimented. Growth of the sequential crops at harvest, yield attributes and yield are presented in Table 5. As the phenology, physiology, architecture, flowering and bearing habits of the sequential crops are different, their statistical comparison will be obsolete and hence presented per se.

Table 6. Rice Equivalent Yield, Land Use Efficiency and Production Efficiencies of cropping sequences in rice-based cropping system (2016 - 19)

Cropping system	REY of sequential crop (kg ha^{-1})	Land Use Efficiency (%)	Production Efficiency (kg ha^{-1} day^{-1})	Economic Efficiency (Rs. ha^{-1} day^{-1})
T_1: Rice-Sesame	1856	57.5	30.2	144.2
T_2: Rice-Groundnut	5028	64.4	47.5	269.2
T_3: Rice -Sunflower	5733	60.3	38.8	230.1
T_4: Rice-Castor	4004	76.7	42.5	162.1
T_5: Rice–Black gram	1867	53.4	40.3	280.0
S.Ed.	1125	2.64	1.75	13.7
CD (P = 0.05)	2669	7.19	5.15	31.8

Land Use Efficiency and Production Efficiency

Rice equivalent yield and efficiencies of cropping systems are presented in Table 6. Rice equivalent yield was the highest in sunflower followed by groundnut and was the lowest in sesame, mainly due to the lower yield of sesame than the other sequential crops experimented with. Land utilization efficiency was the highest (76.7%) in the rice-castor system and lowest (53.4 %) in rice–black gram sequence, which is mainly attributed to the long duration of castor and short duration of black gram in the field. Similar results of rice-black gram cropping sequence recording lowest land utilization efficiency were recorded by Sanjoy and Monalisa (2007). Production efficiency was the highest in the rice-groundnut system followed by the rice-castor system and was the lowest in rice–sesame system. Economic efficiency was the highest in rice–black gram system (Rs. 280 ha^{-1} day^{-1}), followed by rice – groundnut system (Rs. 269 ha^{-1} day^{-1}).

Table 7. Water Use Efficiency and Economics of rice in rice-based cropping sequences (2016 – 19)

Cropping system	Total water used (mm)	WUE (kg/ha.mm)	Cost of Cultivation Rs/ha	Gross returns Rs/ha	Net returns Rs/ha	B : C
T_1: Rice-Sesame	1150	4.57	35000	57396	22396	1.64
T_2: Rice-Groundnut	1150	4.71	35000	59411	24411	1.70
T_3: Rice-Sunflower	1150	4.46	35000	55688	20688	1.59
T_4: Rice-Castor	1150	4.28	35000	53088	18088	1.52
T_5: Rice–Black gram	1150	5.22	35000	59604	24604	1.70
Mean	1150	4.65	35000	58437	23437	

Water Use Efficiency and Economics

Total water consumed was computed by summing the irrigation water applied and the effective rainfall. Effective rainfall was calculated as fifty percent of the total rainfall during the cropping period. The highest water use efficiency of rice (5.22 kg ha^{-1} mm^{-1}) was witnessed in rice–black gram cropping sequence followed by rice–groundnut (4.71 kg ha^{-1} mm^{-1}) and rice-sesame (4.57 kg ha^{-1} mm^{-1}) systems (Table 7) which may be attributed to the higher grain yields of rice obtained in the above systems. Sureshkumar and Pandian, 2017 recorded a water use efficiency of 6.7 kg ha^{-1} mm^{-1} in the SRI method of rice cultivation whilst lower WUE was recorded with a conventional method of rice cultivation.

Table 8. Water Use Efficiency and Economics of sequential crops in rice-based cropping sequences (2016 –19)

Cropping system	Total water used (mm)	WUE (kg/ha. mm)	Cost of Cultivation Rs/ha	Gross returns Rs/ha	Net returns Rs/ha	B : C
T_1: Rice-Sesame	580	1.50	32000	43500	11500	1.36
T_2: Rice-Groundnut	380	3.31	28036	62850	34814	2.24
T_3: Rice-Sunflower	420	5.12	31500	75250	43750	2.39
T_4: Rice-Castor	620	2.36	28000	43950	15950	1.57
T_5: Rice–Black gram	350	2.00	26000	56000	30000	2.15

Although irrespective of cropping sequences, the cost of cultivation was the same for rice, gross returns were highest in rice-black gram system followed by rice –groundnut system because of the enhanced grain yield obtained in the above systems. Net returns and benefit-cost ratio was the highest in rice-black gram system followed by rice-groundnut system and was the lowest in rice-castor system compared to other systems. Patra *et al.* (1989) and Das and Bhanja (1996) also reported that the rice–black gram and rice–field pea relay cropping systems were the most remunerative relay cropping systems.

Table 9. Water Use Efficiency and Economics of rice-based cropping sequences (2016 – 19)

Cropping system	Total water used (mm)	WUE (kg/ha. mm)	Cost of Cultivation Rs/ha	Gross returns Rs/ha	Net returns Rs/ha	B : C
T_1: Rice-Sesame	1730	3.54	67000	100896	33896	1.51
T_2: Rice-Groundnut	1530	4.36	63036	122261	59225	1.94
T_3: Rice-Sunflower	1570	4.63	66500	130938	64438	1.97
T_4: Rice-Castor	1770	3.61	63000	97038	34038	1.54
T_5: Rice–Black gram	1500	4.47	61000	115604	54604	1.90

As far as the sequential crops are concerned, the highest water use efficiency was witnessed in sunflower (5.12 kg/ha mm) followed by groundnut (3.31 kg/ha mm) and the lowest was registered in sesame (Table 8). Net returns were the highest in the sunflower cropping system and the lowest was registered in rice–sesame system. Benefit–cost ratio was also the highest due to sequential cropping with sunflower followed by groundnut (Table 9).

CONCLUSION

Results indicated that of the cropping systems experimented with, rice-black gram and rice-groundnut systems are the most viable options for maintaining soil fertility, improving dry matter production and grain yield of the proceeding rice crop and economic efficiency of the sequences. Sequential cropping with sunflower followed by groundnut impacted its significance in registering higher rice equivalent yield, water use efficiency, net returns and benefit-cost ratio whilst the above parameters were the lowest in rice–sesame system. Amalgamating, the positive impact of the cropping sequences, rice–black gram, rice-sunflower and rice–groundnut cropping sequences can be recommended for water scarce conditions of Parambikulam Aliyar Command area of Tamil Nadu.

REFERENCES

Adisu,T., Anbesse,B. and D.Tamene. 2020. Effect of nitrogen and phosphorus on yield and yield components of Sesame (*Sesamum indicum* L.) at Kamashi Zone of Benshangul Gumuz under Balanced Fertilizer. *Adv. Tech. Biol Med.*, **8**:276.

Ahmad,T., Hafeez,F.Y., Mahmood,T. and K.Malik. 2001. Residual effect of nitrogen fixed by mung bean (*Vigna radiata)* and black gram (*Vigna mungo)* on subsequent rice and wheat crops. *Aus. J. Exp. Agric.,* **41:** 245 – 248.

Cassman,K.G., Olk,D.C., Brouder,S.M. and B.A.Roberts. 1995. The influence of moisture regime, organic matter and root ecophysiology on the availability and acquisition of potassium: Implications for tropical lowland rice. In: Potassium in Asia. Proceedings of the 24th International Colloquium of the International Potash Institute; Basel. Pp. 135–156.

Chuang,F.T. 1973. An analysis of change of Taiwan's cultivated land utilization for recent years. Rural Economic Div. JCRR Rep. 21, Taipei.

Das,N.R. and N.Bhanja. 1996. Effect of sowing condition on yield of paira crops grown after rainy season. *Ind. J. Agron.,* **41(2):** 334–335.

Gangwar,B., Katyal,V. and K.V.Anand. 2004. Stability and efficiency of cropping system in Chhattisgarh and Madhya Pradesh. *Ind. J. Agric. Sci.,* **74 (10):** 521-528.

Ghosh, P.K., Bandypadhyay,K.K.,Wanjari,R.H., Manna,M.C., Mishra, A.K. and M.Mohanty. 2007. Legume effect for enhancing productivity and nutrient use efficiency in major cropping systems - An Indian perspective: A review. *J. Sust. Agrl.,* **30:**61-86.

Ghosh,P.K., Hazra,K.K., Venkatesh,M.S., Praharaj,C.S., Narendra Kumar, Chaitanya Prasad Nath, Ummed Singh and Sati Shankar Singh. 2019. Grain legume inclusion in cereal – cereal rotation increased base productivity in the long run. *Exptl. Agrl.,* 1-17. https://doi.org/ 10.1017/ S0014479719000243.

Gomez,K.A. and A.A. Gomez. 1984. Statistical procedures for agricultural research (2nd ed.). John Wiley and sons, NewYork. 680p.

Government of Tamil Nadu (GoTN). 2019. *Salient Statistics on Agriculture*. 2nd Edition. Agriculture Department, Secretariat, Government of Tamil Nadu, 2019. Pp. 1-380.

Hegde,D.M., Prakash Tiwari, S. and M.Rai. 2003. Crop diversification in Indian Agriculture. *Agric. Situation in India.,* **8**:351 – 354.

Jackson, M.L. 1973. *Soil Chemical Analysis*. Prentice Hall of India, New Delhi, P.498.

Jat,R.A., Dungrani,R.A., Arvadia, M.K. and K.L.Sahrawat. 2012. Diversification of rice (*Oryza sativa* L.) based cropping systems for higher productivity, resource-use efficiency and economic returns in South Gujarat, India. *Archives of Agron. and Soil Sci.*, **58:**561-572

Kakraliya,S.K., Ummed Singh, Abhishek Bohra, Choudhary,K.K., Sandeep Kumar, Ram Swaroop Meena and M.L.Jat. 2018. Nitrogen and Legumes: A Meta Analysis. In: *Legumes for Soil Health and Sustainable Management*. Springer, Singapore.

Kar,A.K., Rai,R. and S.F.Dhua. 1977. Redox potential and pH changes in cropped and fallow soil under submergence. *Fert. Tech.,* **14:** 29-31.

Kumpawat,B.S. 2001. Production potential and economics of different crop sequences. *Ind. J. Agron.*, **46:**421-424

Lampe, K. 1995. Rice Research: Food for 4 billion people. *Geo J.*, **35 (3):** 253 – 259.

Matsushima,S., Tanaka,T. and T. Hoshino. 1966. Analysis, of yield-determining process and its application to yield-prediction and culture improvement of lowland rice. LXXV, Temperature effects on tillering in case of leaves and culm, culm-bases and roots being independently treated. *Proc. Crop Sci. Soc. Japan.* **34:** 478–483.

Nath Chaitanya Prasad, Hazraab,K.K., Narendra Kumar, Praharaj Sati Shankar Singh,C.S., Ummed Singh and Narendra Pratap Singh. 2019. Including grain legume in rice-wheat cropping system improves soil organic carbon pools over time. *Ecol. Engg.*, **129:** 144 - 153.

Olk,D.C. and K.G.Cassman. 1995. Characterization of two chemically extracted humic acid fractions in relation to nutrient availability. ACIAR Proceedings No. 56. Canberra (Australia): ACIAR. P. 131–134.

Olsen,S.R., Cole,C.V., Watanabe,F.S. and L.Dean. 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. United States Department of Agriculture. P. 939.

Patra,S.S, Barik,T. and A.Misra. 1989. Production potential and economics of rice-based relay cropping systems . *IRRI News.,* **13(6) :** 48

Perin,R.K.,Donald,L.W., Edwards, R.M. and R.A. Jack.1979. From agronomic data for farmer recommendations. An Economic Training Manual. *CIMMYT Information Bull.*, **27:** 15-33.

Ponnamperuma, F.N. 1978. Electrochemical changes in submerged soils. In: *Soils and Rice*, IRRI, Los Banos, Philippines. **Pp:** 421 – 441.

Ray, M., Chatterjee,S., Pramanick,M., Mani,P.K., Roy, K. and K.Sengupta. 2009. Diversification of rice – based cropping system and their impact on energy utilization and system production. *J. Crop and Weed.*, **5(1):** 162-165.

Sahrawat, K.L. 2004. Organic matter accumulation in submerged soils. *Adv. Agron.,* **81:**169–201.

Sanford, J.O. and J.E. Hairston. 1984. Effects of N fertilization on yield, growth and extraction of water by wheat following soybean and sorghum. *Agron. J.,* **76:** 623–27.

Sanjoy Saha and Monalisa Moharana. 2007. Production potential and economics of different rice-based relay cropping systems under rainfed shallow lowlands of coastal Orissa. *Oryza.,* **44(2) :** 134-136.

Senaratne, R. and D.S. Ratnasinghe. 1995. Nitrogen fixation and beneficial effects of some grain legumes and green manure crops on rice. *Biol. Fert. Soils.,* **19:** 49-54.

Sinclar,T.R., Tanner, C.B. and J. M. Bennett. 1984. Water use efficiency in crop production. *Biosci.*, **34:** 36–40.

Sravan,U.S., Ramana Murthy,K.V. and G.S.Siva. 2015. Sustainability of rice based cropping system through pre-kharif crops. *Environ. and Ecol.*, **33:**1121-1125.

SravanU.S. and K.V.Ramana Murthy. 2018. Enhancing Productivity in Rice-Based Cropping Systems, Plant Competition in Cropping Systems, Daniel Dunea, IntechOpen, DOI: 10.5772/intechopen.76904

Stanford,G. and L.English. 1949. Use of the Flame Photometer in rapid soil tests for K and Ca. *Agron. J.,* **41(9):**446-447.

Subbiah, B.V. and G.L. Asija. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.,* **25:** 259-260.

Subbian, P., Annadurai, K. and S.P.Palaniappan. 2000. In: *Agriculture: Facts and figures*, Kalyani Publishers, Ludhiana.

Suresh Kumar, R. and B.J. Pandian. 2017. Water production parameters and yield of rice affected by methods of transplanting and irrigation management practices. *Int. J.Curr. Microbiol. App. Sci.,* **6(7):** 142-148.

Tamilezhai, A., Chandra Sekaran, N. and C.Sudhalakshmi. 2018. Effect of different cropping sequences on soil nutrient status, nutrient uptake and crop yield in PAP command area of Tamil Nadu. *Madras Agric. J.,* **105 (4–6):** 170 – 175.

Tomar, S. and A.S. Tiwari. 1990. Production and economics of different crop sequences. *Ind. J. Agron.*, **35(1/2):** 30-35.

Toomsan, B., Mc.Donagh,J.F., Limpinuntana,V. and K.E.Giller. 1995. Nitrogen fixation by groundnut and soyabean and residual nitrogen benefits to rice in farmers' fields in North East Thailand. *Pl. Soil.*, **175:** 45 – 46.

Walkley, A. and I.A.Black. 1934. An examination of the Degtjareff mathod for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Sci.*, **37(1):** 29-38.

Wani, S.P., Rupela, O.P. and K.K. Lee. 1995. Sustainable agriculture in the semi-arid tropics through biological nitrogen fixation in grain legumes. *Pl. Soil.*, **174:** 29-49.

Wasim Ali, Amanullah Jan, Akhtar Hassan, Aqleem Abbas, Altaf Hussain, Murtaza Ali, Syed Ali Zuhair and Ashraf Hussian. 2015. Residual effect of preceding legumes and nitrogen levels on subsequent maize. *Int. J. Agron. and Agrl. Res.,* **7(1):** 78 – 85.

Yoshida S. 1978. Tropical Climate and Its Influence on Rice. Research Paper Series No. 20. International Rice Research Institute, Los Baños, Philippines.