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IDENTIFICATION OF A SUITABLE CROP SEQUENCE MODULE FOR INTEGRATED FARMING SYSTEM OF TELANGANA (INDIA) UNDER IRRIGATED SITUATION

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ABSTRACT

A field experiment was conducted for two years (2017-2019) at the College Farm, AICRP on Integrated Farming Systems unit, PJTSAU, Hyderabad (India) to identify the profitable cropping system module for different integrated farming systems under irrigated situation in sandy loam soils of Southern Telangana zone, Telangana (India). Among the ten cropping systems evaluated, sweet corn-vegetable (tomato) system was found more remunerative with B:C ratio 3.54, followed by okra-marigold-beetroot system with B:C ratio of 2.92. Among the ecological cropping systems for improving the soil health, Bt cotton + green gram (1:3)-groundnut cropping system gave significantly higher rice grain equivalent yield (13,687 kg ha^{-1}), however the net returns were high (₹ 1,37,259 ha^{-1}) in pigeon pea + green gram (1:7)-sesame cropping system. Out of the two systems tested to meet the household nutritional security, pigeon pea + maize (1:3)-groundnut system gave higher rice grain equivalent yield (13,772 kg ha^{-1}) with higher net returns (₹ 1,35,959 ha^{-1}). Within the two fodder crops/cropping systems, fodder maize-lucerne system showed higher B:C ratio (1.64). Fodder systems were more exhaustive than all other cropping systems. However, within two years of experimentation the changes in physicochemical properties and soil fertility status were not significantly affected.

Keywords: Cropping systems, economics, rice grain equivalent yield (RGEY), system productivity, system profitability

INTRODUCTION

The sustainability of Indian agriculture is threatened by sharp declining productivity factor due to the deteriorating soil quality, imbalanced use of fertilizers, mismatch between nutrient additions and removal by crops (Antil, 2012). The food production must keep pace with the country's increasing population, ensuring not only the food security but also nutritional security. Therefore, to achieve sustainable fertility and productivity, efforts must be focused on reversing the trend in soil degradation by adopting efficient cropping systems and soil health management practices. There is need to enhance productivity unit^{-1} area by adopting intercropping systems. Gangwar and Ram (2005) reported that the inclusion of legumes in cropping systems under intensification and interruptive approaches, as per resource availability led to considerable improvement in crop productivity and soil fertility. There is much pressing need to meet the varied food grain and other nutritional requirements of growing population and to sustain a higher productivity level. Hence, there is an urgency to diversify present cropping pattern into new areas like vegetables, fodder, oilseeds, pulses and allied fields crops. Crop diversification shows a lot of promises in alleviating these problems, besides fulfilling the basic needs for cereals, pulses, oilseeds and vegetables and regulating the farm income, withstanding weather aberrations, controlling price fluctuation, ensuring balanced food supply, conserving natural resources, reducing the chemical fertilizer and pesticide loads, ensuring environmental safety and creating employment opportunity (Gill and Ahlawat, 2006).

Rice, maize and Bt cotton are the predominant crops grown either solely or in rotation with other crops in the Sothern Telangana Zone of India. As all these crops are exhaustive, therefore leguminous crops are to be identified to compliment these crops and to improve soil suitability in cropping system module. Hence, a major agricultural research priority is desired to sustain the soil fertility by including legume component in present cropping systems of Telangana (Kumari *et al.*, 2020). Several researchers have reported that the productivity and income are far higher when integrated with other components of agriculture than crops alone. Integrated farming systems benefit from synergisms among different enterprises, diversity of produce and environmental soundness (Behera *et al.*, 2010). In present study the various combinations of crop sequences were evaluated so as to identify best crops and cropping system suitable for farming systems of Southern Telangana zone of Telangana state (India).

Grain and seed samples at harvesting stage were collected, oven dried and ground for the analysis of nitrogen, phosphorus and potassium uptake. The total nitrogen content in dried plant sample was determined by micro-Kjeldhal's distillation method (Piper, 1966). The diacid extract (9:4 nitric acid: perchloric acid) was used for analysis of total phosphorus and potassium in plant samples. Concentration of nutrient was multiplied by yield for calculation of nutrient uptake.

MATERIALS AND METHODS

The study was conducted for two consecutive years from 2017-2019 at the College Farm (All India Coordinated Research Project on Integrated Farming Systems Unit), PJTSAU, Rajendranagr, Hyderabad (India). The soil was sandy loam, low in organic carbon (0.39%), available nitrogen (112 kg ha $^{-1}$), medium in available phosphorus (23.4 kg ha^{-1}) and available potassium (170 kg ha^{-1}). The treatments consisted of ten crop sequences. The experiment was laid out in randomized block design and replicated thrice. The varieties used were rice - 'RNR 15048', groundnut - 'K 6', greengram - 'MGG 295', pigeon pea - 'PRG 176', sesamum - 'Swetha thil', finger millet - 'Hima', fodder sorghum - 'CSH 24 MF' and fodder cowpea - 'Vijaya'. The crops were raised under irrigated conditions with recommended package of practices of the region were followed. To identifying the best crops and cropping systems suitable for farming systems of Southern Telangana zone of Telangana (India), various combinations of crop sequences were evaluated. The ten combinations of cropping systems, evaluated during *kharif, rabi* and *summer* seasons, were grouped into five subsets. The first subset included pre-dominant cropping systems of the region [T_1: rice-maize, and T_2: Bt cotton]. The second subset included ecological cropping systems involving pulses for improving soil health [T_3: Bt cotton + green gram (1:3) - groundnut, and T_4: pigeon pea + green gram (1:6) - sesame]. The third subset comprised of cropping system involving cereals/pulses/oilseeds to meet the household nutritional security [T_5: pigeon pea + maize (1:3) - groundnut, and T_6: pigeon pea + groundnut (1:7) - ragi]. The fourth subset involved cropping systems for round the year green/dry fodder production [T_7: fodder sorghum + fodder cowpea (1:2) - horse gram - sunhemp, and T_8: fodder maize - lucerne]. The fifth subset involved cropping systems comprising of vegetables and other high value crops for income enhancement [T_9: sweet corn - vegetables i.e. tomato, and T_{10}: okra - marigold - beet root]. During *rabi*, crops were taken up as and when the preceding *kharif* crops were harvested in the respective plots. The plot size varied from 8-22 m^2.

The economic yield and stover/straw/stalk yields were recorded individually for all the crops in cropping systems. Yield was recorded in net plot area for each treatment. For comparison of different crop sequences, the yields of all crops were converted into rice grain equivalent yield on existing price basis. Rice equivalent yield (REY) was calculated by using the following formula:

$$REY = Yx(Px/Pr)$$

where Yx = yield of non-rice crops (kg ha^{-1}), Px = price of non-rice crops, and Pr = price of rice crop.

Gross returns were calculated based on market price of produce. BC ratio was worked out by dividing net returns with cost of cultivation. Hence, it was felt necessary to work out a location-specific cropping system for Southern Telangana zone of Telangana, which can utilize resources judiciously to maximize return, protect the environment and meet the day-to-day nutritional requirements of human and livestock. Grain and seed samples at harvest stage were collected, oven-dried and ground for the analysis of nitrogen, phosphorus and potassium uptake. The total nitrogen content in dried plant sample was determined by micro-Kjeldhal's distillation method (Piper, 1966). The diacid extract (9:4, nitric acid: perchloric acid) was used for the analysis of total phosphorus and potassium in plant samples. Concentration of nutrient was multiplied by yield for calculation of nutrient uptake. The statistical analysis was done by using analysis of variance as per standard method (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Productivity and profitability in various cropping systems

The mean performance of different crops in terms of rice grain equivalent yield during *kharif*, 2017 and 2018 indicated that sweet corn crop (T_9) gave significantly higher rice grain equivalent yield over other crops evaluated in different cropping systems (Table 1). Sweet corn and okra were tested under cropping systems involving vegetables and other high value crops for income enhancement and sweet corn with RGEY (rice grain equivalent yield) of 10397 kg and was found to be more remunerative than okra with RGEY of 6662 kg ha^{-1}. Among the ecological cropping systems involving pulses for improving soil health, Bt cotton + green gram (1:3) cropping system recorded significantly higher rice grain equivalent yield (7420 kg ha^{-1}) than pigeon pea + green gram (1:3) (5543 kg ha^{-1}) cropping system. Growing two or more compatible crops on the same piece of land among other benefits increases the crop production (Seran and Brintha, 2009), improves soil fertility (Darmardeh, 2010) and guards against total crop failure (Okpara *et al*., 2004).

Out of the two systems evaluated to meet the household nutritional security involving cereals/ pulses/oilseeds, both pigeon pea + maize (1:3) and pigeon pea + groundnut (1:7) systems showed almost similar RGEY (7386 and 7898 kg ha^{-1}, respectively). Within the two fodder crops/cropping systems tested, fodder sorghum + fodder cowpea (1:2) (4380 kg ha^{-1}) and fodder maize (4510 kg ha^{-1}) systems showed similar RGEY. Rice and Bt cotton, the pre-dominant cropping systems of the region, yielded almost similar rice grain equivalent (6182 and 6335 kg ha^{-1}, respectively). Sreerekha and Dhurva (2010) reported that cotton intercropped with soybean gave 28 and 29% more soybean and seed cotton yield, respectively, over the corresponding sole crops. Due to higher price of green gram, the net returns from Bt cotton intercropped with green gram in 1:3 row ratio system were higher (₹ 48,676 ha^{-1}), followed by Bt cotton intercropped with soybean at 1:3 row ratio (₹ 46,345 ha^{-1}) and Bt cotton intercropped with green gram at 1:2 (₹ 43,425 ha^{-1}). Maximum net returns of ₹ 61,604 were observed in cotton + mung intercrop as compared to other paired row cotton with intercrops (CICR, 2009-2010).

The mean performance of different crops in terms of rice grain equivalent yield during *rabi* and *summer* 2017-2018 and 2018-2019 indicated that out of all the crops, marigold-beetroot tested under cropping systems involving vegetables and other high value crops for income enhancement, recorded

Table 1: Performance of crops under various cropping systems (pooled mean of 2 years; 2017-2018 & 2018-2019)

	Rice grain equivalent yield (kg ha^{-1})											
	Year 2017 - 2018				Year 2018 - 2019				Pooled mean			
Cropping systems	*Kharif*	*Rabi*	*Summer*	System	*Kharif*	*Rabi*	*Summer*	System	*Kharif*	*Rabi*	*Summer*	System
Rice-maize	6085	5698	0	11784	6278	5493	0	11771	6182	5596	0	11778
Bt cotton	6108	0	0	6108	6561	0		6561	6335	0	0	6335
Bt. cotton + green gram (1:3) - groundnut	7012	6281	0	13293	7827	6253	0	14080	7420	6267	0	13687
Pigeon pea + green gram (1:6) - sesame	5594	2719	0	8313	5492	2899	0	8391	5543	2809	0	8352
Maize + pigeon pea (1:3) - groundnut	7406	6444	0	13850	7366	6327	0	13693	7386	6386	0	13772
Pigeon pea + groundnut (1:7) - ragi	7745	2562	0	10306	8052	3188	0	11240	7898	2875	0	10773
Fodder sorghum + fodder cowpea (1:2) – horse gram - sunhemp	4521	841	1863	7225	4239	950	1476	6666	4380	895	1670	6945
Fodder maize - lucerne	4523	3937	0	8461	4497	3212	0	7709	4510	3575	0	8085
Sweet corn - vegetables (tomato)	10379	19136	0	29515	10415	15142	0	25557	10397	17139	0	27536
Okra - marigold - Beetroot	6317	22068	10376	38761	7007	20696	8731	36434	6662	21382	9554	37598
$CD_{0.05}$				2045				1378				1498
SE(m)				683				460				500
CV (%)				8				6				6

2017-18: Sale price for grain (₹. kg^{-1}): Rice = 15.50, maize = 14.25, groundnut = 42.50, okra = 15.00, Bt cotton = 43.20, green gram = 53.75, pigeon pea = 52.50, sweet corn = 10.00, maize = 14.25, tomato = 10.00, sesame = 53.00, finger millet = 19.00, marigold = 30.00 and beetroot = 10.00.

Sale price for stover (₹. kg^{-1}): rice = 1.00, maize = 1.00, okra = 0.25, groundnut = 3.00, green gram = 2.00, Bt cotton = 0.25, pigeon pea = 0.25, fodder sorghum = 2.00, fodder cowpea = 3.00, fodder maize = 2.00, tomato = 0.25, sesame = 0.25, finger millet = 0.25, horse gram = 2.00, sunhemp = 1.50, lucerne = 2.00, marigold = 0.25, and beetroot = 1.00.

2018-19: Sale price for grain (₹. kg^{-1}): Rice = 17.7, maize = 17.00, groundnut = 48.9, okra = 20.00, Bt cotton = 54.50, green gram = 69.75, pigeon pea = 56.75, sweet corn = 9.00, tomato = 10.00, sesame = 62.49, finger millet = 28.97, marigold = 50.00, and beetroot = 10.00.

Sale price for stover (₹. kg^{-1}): Rice = 1.00, maize = 1.00, okra = 0.25, groundnut = 5.00, green gram = 2.00, Bt cotton = 0.25, pigeon pea = 0.25, fodder sorghum = 2.00, fodder cowpea = 3.00, fodder maize = 2.00, tomato = 0.25, sesame = 0.25, finger millet = 0.25, horse gram = 2.00, sunhemp = 1.50, lucerne = 2.00, marigold = 0.25, and beetroot = 0.25.

higher RGEY (21,382 kg ha^{-1}) as compared to the tomato in sweet corn-vegetables system (17,139 kg ha^{-1}) [Table 1 and 2]. However, because of having low cost of cultivation, tomato crop recorded higher B:C ratio compared to marigold - beetroot system. Among the ecological cropping systems involving pulses/green manures and other crops for improving soil health, groundnut crop recorded significantly higher RGEY (6267 kg ha^{-1}) than sesame (2809 kg ha^{-1}) crop. Out of the two systems tested to meet the household nutritional security involving cereals/pulses/oilseeds, groundnut crop recorded significantly higher RGEY (6386 kg ha^{-1}) than ragi (2875 kg ha^{-1}). Out of the two fodder crops/cropping systems, lucerne crop (3575 kg ha^{-1}) resulted in higher RGEY as compared to horse gram - sunhemp crops (895 kg ha^{-1}). Maize, tested as pre-dominant cropping systems of the region in *rabi* after *kharif* rice, recorded higher RGEY of 5596 kg ha^{-1}.

Regarding system productivity, out of all the systems evaluated okra - marigold - beetroot system gave highest RGEY (37,598 kg ha^{-1}) than other crop sequences. Sweet corn - vegetables (tomato) system was next best crop sequence with 27536 kg ha^{-1} RGEY. Nevertheless, due to the increased cost of cultivation in okra - marigold - beetroot cropping system, the sweet corn - vegetables system was more remunerative with BC ratio of 3.54 than okra - marigold - beetroot system in which

Table 2: Economics of crops in various cropping systems (Pooled mean of two years 2017-2018 and 2018-2019)

Cropping sequences	Year 2017 - 2018			Year 2018 - 2019			Pooled mean		
	COC (₹ ha^{-1})	Net returns (₹ ha^{-1})	BC ratio	COC (₹ ha^{-1})	Net returns (₹ ha^{-1})	BC ratio	COC (₹ ha^{-1})	Net returns (₹ ha^{-1})	BC ratio
Rice - maize	80045	102601	1.28	81132	125968	1.55	80588	114284	1.42
Bt cotton	45570	49109	1.08	45820	68995	1.51	45695	59052	1.29
Bt. cotton + green gram (1:3) - groundnut	89000	117048	1.32	90187	157471	1.75	89593	137259	1.53
Pigeon pea + green gram (1:6) - sesame	53050	75809	1.43	54053	93374	1.73	53551	84591	1.58
Maize + pigeon pea + (1:3) - groundnut	91170	123506	1.35	92482	148413	1.60	91826	135959	1.48
Pigeon pea + groundnut (1:7) - ragi	74750	84998	1.14	76106	121233	1.59	75428	103115	1.37
Fodder sorghum + fodder cowpea (1:2) - horse gram - sunhemp	53605	60384	1.13	54489	62643	1.15	54047	61514	1.14
Fodder maize - lucerne	50240	80900	1.61	50613	84939	1.68	50426	82919	1.64
Sweet corn - vegetable (tomato)	99450	358040	3.60	100457	349814	3.48	99954	353927	3.54
Okra - marigold - beetroot	156110	444694	2.85	161691	481785	2.98	158901	463240	2.92

BC ratio was 2.92. Among the ecological cropping systems involving pulses/green manures and other crops for improving the soil health, Bt cotton + green gram (1:3) - groundnut cropping system depicted significantly higher REGY of 13687 kg ha^{-1} and net returns of ₹ 1,37,259 ha^{-1}) than pigeon pea + green gram (1:6) - sesame (8352 kg ha^{-1} and ₹ 84,591, respectively) cropping system. However, because of low cost of cultivation, pigeon pea + green gram (1:6) - sesame recorded higher BC ratio (1.58). If the peak demand for resources varies, less competition will occur and greater yield is recorded in cropping systems.

Out of the two systems assessed to meet the household nutritional security involving cereals/ pulses/ oilseeds, pigeon pea + maize (1:3) - groundnut system recorded higher RGEY of 13772 kg ha^{-1} with high net returns (₹ 1,35,959 ha^{-1}) over pigeon pea + groundnut (1:7) - ragi system. Out of the two fodder crops/cropping systems, fodder maize-lucerne system resulted in higher B:C ratio (1.64) over fodder sorghum + fodder cow pea (1:2) - horse gram - sunhemp system (1.14). In any inter-cropping system, competition for various resources by the component crops is obvious. The extent of competition is, however, influenced by the type of crop species involved. Intercropping with legumes is reported to fix nitrogen which ensures positive complementary interaction (Fatokun *et al.*, 2000). Other rice - maize and Bt cotton were the pre-dominant cropping systems of Southern Telangana zone, and recorded higher B:C ratio in case of rice - maize system (1.42) as compared to Bt cotton alone (1.29). In two years, cotton - legume - corn rotation enhanced yield to the tune of 11% as compared to the continuous cotton grown without legumes (Sankaranarayanan *et al.*, 2010). Six Bt cotton based double cropping systems *viz*., two millets, two pulses and two oilseed crops were evaluated to identify the most profitable, productive and sustainable system. Amongst them, Bt cotton - maize yielded highest seed cotton equivalent (CICR, 2009-2010). Banik and Sharma (2009) also reported that cereal - legume intercropping systems were superior to mono-cropping.

Nutrient uptake

Pooled nutrient uptake by various crops and cropping systems varied significantly during 2017-2019 and data on the uptake of nitrogen, phosphorus and potassium are presented in Table 3.

Nitrogen uptake: During *kharif*, among the crops and cropping systems evaluated, fodder crops were found more exhaustive. Out of the two fodder crops/cropping systems, fodder sorghum + fodder - cow pea (1:2) fodder system removed maximum nitrogen (532.3 kg ha^{-1}). This was followed by fodder maize (392.4 kg ha^{-1}). Among the ecological cropping systems involving pulses/green manures

Table 3: Pooled nutrient uptake (kg ha^{-1}) by crops under various cropping systems during 2017-2019

Treatments	Pooled N uptake *kharif*	Pooled N uptake *rabi*	Pooled P uptake *kharif*	Pooled P uptake *rabi*	Pooled K uptake *kharif*	Pooled K uptake *rabi*
Rice – maize	191.3	139.7	53.2	60.6	240.2	161.6
Bt cotton	180.8	0.0	18.7	0.0	122.4	0.0
Bt cotton + green gram (1:3) - ground nut	200.8	121.7	21.5	15.0	125.1	33.5
Pigeon pea + green gram (1:6) – sesame	170.2	65.5	19.0	13.7	88.4	29.0
Pigeon pea + maize (1:3) – groundnut	260.9	126.1	61.8	15.0	197.7	34.3
Pigeon pea + groundnut (1:7) – ragi	267.9	123.0	29.0	17.7	111.1	45.2
Fodder sorghum + fodder cow pea (1:2) - horse gram – sunhemp	532.3	357.4	46.4	27.2	314.7	332.5
Fodder maize – lucerne	392.4	441.9	59.8	27.1	703.7	301.0
Sweet corn - vegetables (tomato)	345.0	359.5	105.8	47.7	440.8	186.7
Okra - marigold – beetroot	84.0	473.7	17.4	78.8	123.5	278.4
$CD_{0.05}$	32.9	20.8	7.1	5.7	34.5	18.8
SE(m)	11.0	6.9	2.4	1.9	11.5	6.3
CV (%)	7.2	5.4	9.5	10.9	8.1	7.8

and other crops for improving soil health, nitrogen removal by both the systems was statistically at par. However, Bt cotton + green gram (1:3) cropping system removed slightly higher quantities of nitrogen (200.8 kg ha^{-1}) than pigeon pea + green gram (1:3) cropping system (170.2 kg ha^{-1}). Out of the two systems tested to meet the household nutritional security involving cereals/pulses /oilseeds, both maize + pigeon pea (1:3) and pigeon pea + groundnut (1:7) systems removed almost similar quantities of nitrogen (260.9 and 267.9 kg ha^{-1}, respectively). Sweet corn and okra were tested under cropping systems involving vegetables and other high value crops for income enhancement and sweet corn was found more exhaustive with 345.0 kg ha^{-1} nitrogen removal than okra (84.0 kg ha^{-1}). Rice and Bt cotton were tested as pre-dominant cropping systems (check) of the region and nitrogen removal by both the crops was at par.

During *rabi* and summer, marigold - beetroot removed maximum nitrogen (473.7 kg ha^{-1}) and was closely followed by lucerne crop (441.9 kg ha^{-1}). Lowest nutrient uptake was observed in sesame (65.5 kg ha^{-1}). In terms of system uptake, rice - maize and Bt cotton were tested as pre-dominant cropping systems (check) of the region and nitrogen removal by rice - maize was higher (331.0 kg ha^{-1}). Out of the two fodder crops/cropping systems, the nitrogen uptake was maximum in fodder sorghum + fodder cow pea (1:2) - horse gram - sunhemp fodder system (889.7 kg ha^{-1}), followed by fodder maize - lucerne system (834.3 kg ha^{-1}). Among the ecological cropping systems involving pulses/green manure and other crops for improving soil health, nitrogen removal by Bt cotton + green gram (1:3) - groundnut cropping system was slightly higher (322.5 kg ha^{-1}) than pigeon pea + green gram (1:6) - sesame cropping system (235.7 kg ha^{-1}). Of the two systems tested to meet the household nutritional security involving cereals/pulses/oilseeds, both pigeon pea + maize (1:3) - groundnut and pigeon pea + groundnut (1:7) - ragi systems removed almost similar amount of nitrogen (387.0 and 390.9 kg ha^{-1}, respectively). Sweet corn - vegetables (tomato) system (704.5 kg ha^{-1}) and okra - marigold - beetroot (557.7 kg ha^{-1}) systems were tested under cropping systems involving vegetables and other high value crops for income enhancement and the former was found to be more exhaustive.

Phosphorus uptake: During *kharif*, among the crops and cropping systems tested sweet corn was found to be more exhaustive with higher phosphorus removal (Table 3). In case of fodder crops/ cropping systems, both fodder sorghum + fodder cow pea (1:2) (46.4 kg ha^{-1}) and fodder maize (59.8 kg ha^{-1}) removed significantly quantities of phosphorus. Among the ecological cropping systems involving pulses/green manure and other crops for improving soil health, phosphorus removal by both the systems was at par. However, Bt cotton + green gram (1:3) cropping system removed slightly higher quantities of phosphorus (21.5 kg ha^{-1}) than pigeon pea + green gram (1:3) cropping system (19 kg ha^{-1}). Out of the two systems tested to meet the household nutritional security involving cereals

/pulses/oilseeds, maize + pigeon pea (1:3) system removed significantly higher quantities of phosphorus (61.8 kg ha^{-1}) than pigeon pea + groundnut (1:7) system (29 kg ha^{-1}). Sweet corn and okra were tested under cropping systems involving vegetables and other high value crops for income enhancement. Sweet corn was found more exhaustive with six times higher phosphorus removal (105.8 kg ha^{-1}) than okra (17.4 kg ha^{-1}). Rice and Bt cotton were tested as pre-dominant cropping system of the region and phosphorus removal by rice (53.2 kg ha^{-1}) was significantly higher than Bt cotton (18.7 kg ha^{-1}).

During *rabi* and *summer*, marigold - beetroot removed maximum phosphorus (78.8 kg ha^{-1}), followed by maize crop (60.6 kg ha^{-1}) [Table 3]. Lowest nutrient uptake was observed with sesame (13.7 kg ha^{-1}). In terms of system uptake, rice - maize and Bt cotton were evaluated as pre-dominant cropping systems (check) of the region and phosphorus removal by rice - maize was 113.8 kg ha^{-1}. Of the two fodder crops/cropping systems tested, the phosphorus uptake was high in fodder maize - lucerne system (86.9 kg ha^{-1}) Among the ecological cropping systems involving pulses/green manure and other crops for improving soil health, phosphorus removal was slightly higher in Bt cotton + Green gram (1:3) - groundnut cropping system (36.5 kg ha^{-1}) than pigeon pea + green gram (1:6) - sesame cropping system (32.7 kg ha^{-1}); however both were at par. Of the two systems tested to meet the household nutritional security involving cereals/pulses/oilseeds, both pigeon pea + maize (1:3) - groundnut (76.8 kg ha^{-1}) removed significantly more phosphorus than pigeon pea + groundnut (1:7) - ragi system (46.7 kg ha^{-1}). Of the two cropping systems involving vegetables and other high value crops for income enhancement, sweet corn - vegetables (tomato) system showed phosphorus uptake of 153.5 kg ha^{-1} and was more exhaustive, while okra - marigold - beetroot system showed uptake of 96.2 kg ha^{-1}

Potassium uptake: Among the crops and cropping systems during *kharif* fodder maize was found more exhaustive with more potassium removal (Table 3). Fodder maize removed significantly higher potassium (703.7 kg ha^{-1}) than fodder sorghum + fodder cow pea fodder system (314.7 kg ha^{-1}). Among the ecological cropping systems involving pulses/green manure/other crops for improving soil health, Bt cotton + green gram cropping system removed significantly more potassium (125.1 kg ha^{-1}) than pigeon pea + green gram cropping system (88.4 kg ha^{-1}). In the systems tested for household nutritional security involving cereals/pulses/oilseeds, maize + pigeon pea removed significantly higher potassium (197.7 kg ha^{-1}) than pigeon pea + groundnut system (111.1 kg ha^{-1}). Sweet corn and okra were tested under cropping systems involving vegetables and other high value crops for income enhancement and sweet corn was fund 3.5 times more exhaustive with potassium removal of 440.8 kg ha^{-1} than okra. Rice and Bt cotton were tested as pre-dominant cropping system of the region and potassium removal by rice crop (240.2 kg ha^{-1}) was two times higher than Bt cotton (122.4 kg ha^{-1}).

During *rabi* and *summer*, horse gram - sunhemp (332.5 kg ha^{-1}) system removed maximum potassium and was followed by lucerne crop (30.0 kg ha^{-1}) [Table 3]. Lowest nutrient uptake was observed with in sesame (29.0 kg ha^{-1}). In terms of system uptake, rice - maize and Bt cotton were tested as pre-dominant cropping systems of the region and potassium removal by rice - maize was higher (401.8 kg ha^{-1}). Of the two fodder crops/cropping systems the potassium uptake was higher in fodder maize - lucerne system (1004.7 kg ha^{-1}). Among the ecological cropping systems involving pulses/green manure and other crops for improving soil health, potassium removal by Bt cotton + green gram - groundnut cropping system was higher than pigeon pea + green gram (1:6) - sesame cropping system. Among the two systems tested to meet the household nutritional security involving cereals/pulses/oilseeds, both pigeon pea + maize (1:3) - groundnut (232.0 kg ha^{-1}) removed more potassium than pigeon pea + groundnut (1:7) - ragi system (156.3 kg ha^{-1}). Under cropping systems involving vegetables and other high value crops for income enhancement, sweet corn - vegetables (tomato) system was found significantly more exhaustive than okra - marigold - beetroot system.

Soil fertility

The soil pH, EC and available nutrient status of experimental soil were studied at the end of crop sequence (Table 4). Within two years of experimentation the changes in physicochemical properties

Table 4: Changes in soil properties at the end of crop sequence during 2018-2019

Cropping sequence	pH	EC (dS m^{-1})	OC (%)	Avail. N (kg ha^{-1})	Avail. P (kg ha^{-1})	Avail. K (kg ha^{-1})
Rice – maize	7.59	0.41	0.35	154.7	36.1	200.7
Bt cotton	7.91	0.46	0.38	179.8	32.5	202.2
Bt cotton + green gram (1:3) - groundnut	7.54	0.47	0.42	192.3	44.6	200.9
Pigeon pea + green gram (1:6) – sesame	7.77	0.52	0.45	204.9	47.7	225.2
Pigeon pea + maize (1:3) – groundnut	7.61	0.46	0.38	146.3	47.5	195.8
Pigeon pea + groundnut (1:7) – ragi	7.74	0.46	0.44	192.3	48.7	214.5
Fodder sorghum + fodder cowpea (1:2) - horse gram – sunhemp	7.10	0.40	0.42	196.5	42.6	202.6
Fodder maize – lucerne	7.24	0.50	0.42	213.2	51.3	205.0
Sweet corn - vegetables (tomato)	7.15	0.43	0.38	234.2	36.3	192.2
Okra - marigold – beetroot	7.57	0.49	0.41	200.7	42.1	207.1
SEm $\pm$	0.18	0.03	0.01	1.9	4.4	6.2
$CD_{0.05}$	Ns	ns	0.03	ns	ns	ns
CV (%)	4.17	10.04	4.04	15.49	17.90	7.02

The initial soil properties were pH 7.81, electric conductivity (EC) 0.11 dS m^{-1}, organic carbon (OC) 0.39% and available N, P and K 112.2, 23.4 and 170.3 kg ha^{-1}, respectively.

and soil fertility status were insignificant, except for organic carbon which was higher in pigeon pea + green gram (1:6) - sesame crop sequence as compared to the other cropping systems evaluated.

Conclusion: Under high value crops, sweet corn-vegetable system (tomato) was more remunerative followed by okra - marigold - beetroot system. Among the ecological cropping systems, pigeon pea + green gram (1:6) - sesame, under the cropping systems for household nutritional security, pigeon pea + maize (1:3) - groundnut system and under two fodder crops/cropping systems, fodder maize - lucerne system were most profitable and can be suggested for different integrated farming system models of Southern Telangana Zone of Telangana (India) under irrigated situation.

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