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Sustainable rainfed crop sequence based on rainfall analysis under semi-arid vertisol

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ABSTRACT

Based on field experiments conducted with 12 crop sequences (groundnut-groundnut, groundnut-cotton, groundnut-castor, groundnut-pearl millet, groundnut-sesame, cotton-cotton, cotton-castor, cotton-pearl millet, cotton-sesame, castor-castor, pearl millet-pearl millet and sesame-sesame) with 3 fertilizer treatments (control, integrated nutrient management (INM) and recommended dose of fertilizer for different crops) during 1999 to 2005, a statistical selection is made to identify an efficient crop sequence for attaining maximum sustainable yield in a semi-arid Vertisol at Rajkot, Gujarat state. The results revealed that rainfall in individual month, differences of crop sequences, fertilizer treatments and their interaction were significant for groundnut pod equivalent yield. Based on ranking of crop sequences for mean yield and sustainable yield index, groundnut–sesame was found to be highly efficient.

Key words: Crop sequence, nutrient management, rainfall, sustainable yield index.

Groundnut (*Arachis hypogea* L.) is the most important crop grown in Saurashtra region in Gujarat, India. It is an important commercial crop in rainfed areas in Gujarat, Andhra Pradesh, Karnataka and other states of the country. The crop contributes about 40% to the total oilseed production in the country. The mean yield in *kharif* is about 900 kg ha^{-1}, while it is about 1500 kg ha^{-1} in *rabi / summer*. Increasing its productivity in rainfed areas seems possible with an efficient rain water management, integrated nutrient management and suitable crop rotation under rainfed conditions.

In Saurashtra region, farmers grow groundnut every year as a sole crop without any suitable crop rotation. Suitable fertilizer management is desired for the crop to attain a sustainable yield over a period. Among different factors, rainfall distribution during crop growing period would significantly influence yield of groundnut under rainfed conditions. Venkateswarlu and Singh (1982) described response of rainfed crops to applied nutrients under limited water conditions. Prihar and Gajri (1988) described strategies for rationalizing fertilizer application in relation to seasonal water supply and innate soil fertility. Regression models of yield through crop seasonal rainfall were calibrated to identify an efficient crop sequence for rainfed conditions (Draper and Smith, 1998; Maruthi Sankar, 1986). The sustainability of a crop sequence could be assessed using the procedure discussed by Vittal *et al.,* (2002, 2003) for rainfed crops.

MATERIALS AND METHODS

A field experiment was conducted with 12 crop sequences of 5 rainfed crops viz., groundnut-GG-2, castor-GAUCH-1, sesame-Guj-Til-1, cotton-HY-8 and pearl millet-GHB-316 (groundnut-groundnut, groundnut-cotton, groundnut-castor, groundnut-pearl millet, groundnut-sesame, cotton-cotton, cotton-castor, cotton-pearl millet, cotton-sesame, castor-castor, pearl millet-pearl millet and sesame-sesame) alongwith 3 fertilizer treatments (control, integrated nutrient management (INM) and recommended dose of fertilizer for different crops during 1999 to 2005 in a semi-arid Vertisol at Targhadia under All India Coordinated Research Project for Dry land Agriculture. An inter-row spacing of 45 cm was adopted for groundnut, sesame and pearl millet, while a spacing of 90 cm for cotton and castor. The crops were grown in a net plot size of 7.2 m x 6 m. A recommended seed rate of 3 kg ha^{-1} for sesame, 3.75 kg ha^{-1} for pearl millet, 10 kg ha^{-1} each for castor and cotton, and 100 kg ha^{-1} for groundnut were adopted. All recommended agronomic practices were followed for different crops. The field was divided into 3 main plots for control, INM and RDF treatments and 12 sub-plots for testing the 12 crop sequences in a split-plot design with 2 replications.

The dates of sowing and harvest of crops, crop duration and seasonal rainfall received in June, July, August and September during 1999 to 2005 are given in Table 1. The earliest date of sowing was on 18th June in 2001 and 2004, while the latest was on 6th July in 2000 for all crops. The date of harvest was different for all crops.

Rainfall and its distribution in different years

The seasonal rainfall during seven years was in a range of 211 mm (18 rainy days) in 1999 to 1041 mm (33 rainy days) in 2005. A mean rainfall of 123.4 mm (with a variation of 84%) in June, 209.4 mm (57.5%) in July, 147.2 mm (70.7%) in August and 63.2 mm (199.8%) in September was received during the study period which reflects high variability. June received a rainfall in the range of from 5.1

Table 1: Date of sowing (DOS) and harvest (DOH) of crops and rainfall received

Variable	1999	2000	2001	2002	2003	2004	2005	Mean	CV
DOS	22-Jun	6-Jul	18-Jun	2-Jul	19-Jun	18-Jun	23-Jun		
DOH									
Sesame	21-Sep (92)	25-Sep (82)	12-Sep (87)	25-Sep (86)	12-Sep (86)	10-Sep (85)	26-Sep (96)		
Pearl millet	18-Oct (119)	25-Sep (82)	19-Sep (94)	3-Oct (94)	11-Sep (85)	16-Sep (91)	22-Sep (92)		
Groundnut	20-Nov (152)	17-Oct (104)	3-Oct (108)	19-Oct (110)	27-Sep (101)	5-Oct (110)	10-Oct (110)		
Castor	9-Dec (171)	1-Nov (119)	10-Dec (176)	1-Nov (123)	25-Nov (160)	19-Nov (155)	22-Nov (153)		
Cotton	9-Dec (171)	21-Nov (139)	10-Dec (176)	25-Nov (147)	8-Dec (170)	3-Dec (169)	9-Dec (170)		
RD	13	17	35	10	41	26	33	25	46.6
CRF	211	367	424	309	803	649	1041	543.3	55.1
June	56.9	5.1	71.9	207.5	211.8	40.4	270.5	123.4	84.0
July	97.7	273.5	216.0	4.8	356.9	289.7	227.5	209.4	57.5
August	12.7	74.5	115.8	91.0	222.7	318.8	194.6	147.2	70.7
September	43.6	13.4	19.8	6.1	11.8	0	348.0	63.2	199.8

Table 2 : Mean and coefficient of variation of groundnut pod equivalent yield (PEY-kg ha^{-1}) attained by fertilizer treatments under different crop sequences (1999 to 2005)

Crop sequence	Control		Integrated nutrient management			Recommended dose of fertilizer		
	Mean yield	CV	Mean yield	CV	INC	Mean yield	CV	INC
Groundnut–groundnut	644	92	996	86	55	891	68	38
Groundnut–cotton	556	81	556	90	0	498	80	-10
Groundnut–castor	566	48	722	65	28	704	56	24
Groundnut–pearl millet	488	80	646	64	32	648	57	33
Groundnut–sesame	686	80	1121	76	63	933	80	36
Cotton–cotton	439	112	435	88	-1	339	72	-23
Cotton–castor	451	53	733	60	63	648	55	44
Cotton–pearl millet	307	72	556	87	81	539	63	76
Cotton–sesame	601	89	789	85	31	783	89	30
Castor–castor	429	41	591	37	38	591	47	38
Pearl millet–pearl millet	291	51	455	46	56	406	38	40
Sesame–sesame	471	75	706	96	50	772	85	64
Mean	494	73	692	73	41	646	66	32
Critical difference (5%) comparing crop sequences								368
Critical difference (5%) for comparing fertilizer treatments								55
Critical difference (5%) for comparing fertilizer treatments at same crop sequence								191
Critical difference (5%) for comparing crop sequences at same fertilizer								397

CV : Coefficient of variation (%) INC : Increase over control (%) PEY: kg ha^{-1}

mm in 2000 to 270.5 mm in 2005. September had 'no rainfall' in 2004 compared to a maximum of 348 mm in 2005.

Statistical model of yield through rainfall and its distribution

The differences in groundnut pod equivalent yield attained by different crop sequences, fertilizer treatments, and their interaction were tested based on Analysis of Variance (Gomez and Gomez, 1985). Using Least Significant Difference, the yield differences between crop sequences and fertilizer treatments were tested and significantly superior crop sequences identified. The influence of rainfall received in June, July, August and September on pod equivalent yield of groundnut attained under different crop sequences with INM, RDF and control treatments were assessed based on a regression model:

$$Y = \pm a \pm b1\,(RF\ Jun) \pm b2\,(RF\ Jul) \pm b3\,(RF\ Aug) \pm b4\,(RF\ Sep) \quad \ldots\ldots\ldots (1)$$

Table 3: Correlation of groundnut pod equivalent yield of different crop sequences with rainfall received in different months

Month	GN–GN	GN–CO	GN–CA	GN–PM	GN–SE	CO–CO	CO–CA	CO–PM	CO–SE	CA–CA	PM–PM	SE–SE
Integrated nutrient management												
Jun	0.12	-0.48	0.26	-0.33	-0.23	-0.46	-0.13	-0.47	-0.27	0.13	0.19	-0.17
Jul	0.34	0.45	0.70*	0.46	0.75*	0.70*	0.76*	0.63	0.74*	0.40	0.47	-0.14
Aug	0.16	0.70*	0.95**	0.74*	0.96**	0.73*	0.85*	0.75*	0.54	0.70*	0.31	-0.13
Sep	0.01	-0.40	0.39	-0.32	-0.46	-0.40	0.24	-0.24	-0.37	0.13	-0.08	-0.31
Recommended dose of fertilizer												
Jun	0.22	-0.51	0.07	-0.13	-0.17	-0.47	-0.15	-0.55	-0.12	-0.38	-0.01	-0.17
Jul	0.42	0.32	0.43	0.40	0.70*	0.62	0.71*	0.66	0.71*	0.44	0.18	0.15
Aug	0.28	0.71*	0.83*	0.80*	0.89*	0.76*	0.79*	0.54	0.54	0.65	0.26	0.07
Sep	0.24	-0.24	0.39	-0.06	-0.39	-0.27	0.29	-0.18	-0.27	-0.07	-0.08	-0.29
Control												
Jun	0.02	-0.08	-0.02	-0.38	-0.40	-0.70*	-0.48	-0.70*	-0.19	-0.41	-0.28	-0.39
Jul	0.18	0.60	0.71*	0.47	0.72*	0.36	0.51	0.57	0.63	0.22	0.33	-0.04
Aug	0.10	0.74*	0.93**	0.76*	0.75*	-0.03	0.50	0.36	0.36	0.39	-0.03	-0.10
Sep	0.13	-0.49	0.19	-0.35	-0.39	-0.33	0.14	-0.36	-0.27	0.16	-0.31	-0.39

* and ** indicate significance at 5 and 1% level GN : Groundnut CO : Cotton
CA : Castor PM : Pearl millet SE : Sesame

The influence of monthly rainfall on pod equivalent yield was assessed based on the estimates of coefficient of determination (R^2), prediction error (F) and regression coefficients 'b1 to b4' of rainfall occurrence in different months. Using mean pod equivalent yield of a crop sequence 'i' ($\hat{A}_i$) over years; prediction error (Öi) based on model (1); and maximum pod equivalent yield (Y_{max}) attained by any crop sequence in the study period, the sustainable yield index h of a crop sequence 'i' was derived following Vittal *et al.*, (2002, 2003) as

$$h_i = [(\hat{A}_i - Öi) / (Y_{max})] * 100 \quad \ldots\ldots\ldots\ldots (2)$$

A crop sequence under rainfed conditions with maximum value of 'h' was identified.. Based on rank sum, an efficient crop sequence which has the lowest rank sum was identified for adoption under semi-arid Vertisols in Saurashtra region.

RESULTS AND DISCUSSION

Analysis of variance of yield

Crop sequences and their interaction for groundnut pod equivalent yield (PEY) were found to be significantly different in individual and pooled over years (Table 2). Application of INM gave maximum mean PEY in the range of 435 kg ha^{-1} with variation of 88% under cotton–cotton to 1121 kg ha^{-1} with variation of 76% under groundnut–sesame sequence. Compared to this, RDF gave mean yield in the range of 339 kg ha^{-1} (cv. 72%), under cotton–cotton to 933 kg ha^{-1} with variation of 80% under groundnut–sesame sequence. Under control, the mean yield ranged from 291 kg ha^{-1} (cv. 51%), under pearl millet–pearl millet to 686 kg ha^{-1} (cv. 80%), under groundnut–sesame sequence. The increase in mean PEY due to fertilizer application over control ranged from –1 to 81% under INM and –23 to 76% under RDF for cotton–cotton and cotton–pearl millet crop sequences respectively.

Groundnut–sesame sequence was superior with a significantly higher PEY compared to cotton–cotton, castor–castor, pearl millet–pearl millet, cotton–pearl millet and groundnut–cotton. INM and RDF were at par with each other, but gave a significantly higher PEY over control (Table 2). Under INM, groundnut–sesame was superior compared to groundnut–cotton, groundnut–castor, groundnut–pearl millet, cotton–cotton, cotton–pearl millet, castor–castor, pearl millet–pearl millet, sesame–sesame. Under RDF, groundnut–sesame and groundnut–groundnut were superior to cotton–cotton and pearl millet–pearl millet.

Correlation of yield attained with crop seasonal rainfall

The estimates of correlation of rainfall received in June, July, August and September with groundnut PEY attained under 12 crop sequences over years are given in Table 3. The correlations indicated that August rainfall had a significant positive correlation with yield attained under 8 crop sequences with INM application compared to 6 sequences with application of RDF. The relation was significant under groundnut–cotton, groundnut–castor, groundnut–pearl millet and groundnut–sesame in control treatment. Rainfall received in July had a significant positive correlation with yield of groundnut–castor, groundnut–

Table 4: Regression models of groundnut pod equivalent yield through rainfall

Statistic	GN–GN	GN–CO	GN–CA	GN–PM	GN–SE	CO–CO	CO–CA	CO–PM	CO–SE	CA–CA	PM–PM	SE–SE
Integrated nutrient management												
α	208	488	38	492	404	170	288*	343	2	404	178	951
β1(Jun)	2.81	-3.17	-0.55	-1.94	1.19	-1.74	-2.39	-3.26*	0.09	-0.21	1.08	0.10
β2(Jul)	3.74	-1.06	1.51*	-0.76	3.23*	0.59	2.67*	-0.06	3.51*	-0.16	1.11	-0.59
β3(Aug)	-1.80	4.82**	3.81**	3.94	3.74**	2.70*	3.37**	4.16**	1.23	1.61	-0.31	-0.20
β4(Sep)	-1.23	-0.47	1.32	-0.44	-3.87	-0.64	1.66	0.27	-2.22	0.16	-0.68	-1.67
R^2	0.18	0.94*	0.93*	0.84	0.95*	0.91*	0.92*	0.94*	0.72	0.49	0.38	0.11
Φ	1345	209	135	285	148	112	156	151	620	274	283	1102
η	-31.1	31.0	52.4	32.2	86.8	28.8	51.5	36.1	15.1	28.3	15.3	-35.3
Recommended dose of fertilizer												
α	243	599	479	489	83	235*	353	419	-153	565	351	663
β1(Jun)	1.38	-3.38	-2.17	-1.70	1.30	-1.61*	-2.26*	-2.51	1.21	-2.15	0.02	0.25
β2(Jul)	2.55	-1.50	-1.15	-1.14	3.39*	-0.09	0.36	0.68	3.83	-0.60	0.03	0.90
β3(Aug)	-0.59	4.04*	4.17*	4.01*	3.22*	2.17**	2.68*	1.72	0.87	2.55	0.37	-0.04
β4(Sep)	0.48	0.57	1.91*	0.29	-3.16	0.05	1.66*	0.56	-2.27	0.68	-0.14	-1.65
R^2	0.26	0.89	0.91*	0.81	0.93*	0.91*	0.90*	0.82	0.63	0.79	0.08	0.11
Φ	910	225	146	283	113	143	192	248	729	223	254	1078
η	-1.7	24.4	49.8	32.6	73.1	17.5	40.7	26.0	4.8	32.8	13.6	-27.3
Control												
α	461	-22	306	357	544	570	460*	289	26	519	232	658
β1(Jun)	-0.22	1.14	-1.19*	-2.06	-1.89*	-3.01	-2.41*	-1.59	0.59	-1.79	0.07	-0.91
β2(Jul)	0.91	1.04	-0.21	-0.82	0.31	1.52	-0.11	0.5	3.07	-0.63	0.71	-0.24
β3(Aug)	-0.17	2.62*	2.75**	3.97*	2.57*	-0.63	1.55	0.72	-0.31	1.36	-0.52	0.12
β4(Sep)	0.69	-2.60*	-0.72	-0.43	-1.05	0.22	1.31	0.07	-1.49	0.99	-0.37	-0.66
R^2	0.05	0.90*	0.92*	0.92*	0.91*	0.55	0.91*	0.77	0.48	0.76	0.28	0.19
Φ	998	185	146	163	170	572	189	182	669	148	219	552
η	-31.6	33.1	37.5	29.0	46.0	-11.9	23.4	11.2	-6.1	25.1	6.4	-7.2

* and ** indicate significance at 5 and 1% level α : Intercept R^2 : Coefficient of determination
Φ : Prediction error (kg ha^{-1}) η: Sustainable yield index β1 to β4 : Regression coefficients

sesame, cotton–cotton, cotton–castor and cotton–sesame under INM; compared to groundnut–sesame, cotton–castor and cotton–sesame under RDF; and groundnut–castor and groundnut–sesame under control. The rainfall received in June had a significant negative correlation with yield attained under cotton–cotton and cotton–pearl millet in control, while September rainfall had no significant correlation with yield attained by any fertilizer treatment under any crop sequence. Yield attained under groundnut–sesame sequence had a maximum and significant correlation with rainfall received in different months during crop growing season compared to other sequences.

Regression models of yield through crop seasonal rainfall

Based on regression models of PEY of each crop sequence calibrated through monthly rainfall over years, it is observed that the models of groundnut–cotton, groundnut–castor, groundnut–sesame, cotton–cotton, cotton–castor and cotton–pearl millet sequences with INM application gave a significant yield predictability of 0.91 to 0.95 over years. Under RDF application, the models of groundnut–castor, groundnut–sesame, cotton–cotton and cotton–castor sequences gave a significant yield predictability of 0.90 to 0.93, while the models of control yield gave a significant predictability of 0.90 to 0.92 under groundnut–cotton, groundnut–castor, groundnut–pearl millet, groundnut–sesame and cotton–castor sequences. The regression coefficients of effects of monthly rainfall on PEY under INM, RDF and control under 12 crop sequences, R^2, prediction error (F) and sustainable yield index (h) are given in Table 4.

Under INM application, July rainfall had a significant positive effect on PEY under groundnut–castor, groundnut–sesame, cotton–castor and cotton–sesame; while August rainfall had a significant positive effect on yield under groundnut–cotton, groundnut–castor, groundnut–sesame, cotton–cotton, cotton–castor and cotton–pearl millet. June rainfall had a significant negative effect on yield attained under cotton–pearl millet, while September rainfall had no significant effect on yield attained under any sequence.

Under RDF application, July rainfall had a significant positive effect on pod equivalent yield under groundnut–sesame. June rainfall had a significant negative effect under

Table 5: Ranking of different crop sequences under fertilizer treatments

Crop sequence	Control					Integrated nutrient management						Recommended dose of fertilizer					
	μ	CV	Φ	η	Z	μ	CV	K	Φ	η	Z	μ	CV	K	Φ	η	Z
GN–GN	2	11	12	12	37	2	8	5	12	11	38	2	7	5	11	11	36
GN–CO	5	9	6	3	23	10	11	11	6	6	44	10	9	11	6	7	43
GN–CA	4	2	1	2	9	5	5	10	2	2	24	5	4	10	3	2	24
GN–PM	6	7	3	4	20	7	4	8	9	5	33	7	5	8	9	5	34
GN–SE	1	8	4	1	14	1	6	2	3	1	13	1	10	7	1	1	20
CO–CO	9	12	10	11	42	12	10	12	1	7	42	12	8	12	2	8	42
CO–CA	8	4	7	6	25	4	3	3	5	3	18	6	3	3	4	3	19
CO–PM	11	5	5	7	28	9	9	1	4	4	27	9	6	1	7	6	29
CO–SE	3	10	11	9	33	3	7	9	10	10	39	3	12	9	10	10	44
CA–CA	10	1	2	5	18	8	1	7	7	8	31	8	2	6	5	4	25
PM–PM	12	3	8	8	31	11	2	4	8	9	34	11	1	4	8	9	33
SE–SE	7	6	9	10	32	6	12	6	11	12	47	4	11	2	12	12	41

μ : Mean yield CV : Coefficient of variation Φ : Prediction error
K : Yield increase over control η : Sustainable yield index Z : Rank sum

cotton–cotton and cotton–castor, while September rainfall had a significant positive effect on yield under groundnut–castor and cotton–castor sequences.

Under control, August rainfall had a significant positive effect on pod equivalent yield attained under groundnut–cotton, groundnut–castor, groundnut–pearl millet and groundnut–sesame. September rainfall had a significant negative effect on yield attained under groundnut–cotton sequence. July rainfall had no significant effect on yield under any crop sequence.

Sustainable yield index

The estimates of sustainable yield index of different crop sequences are given in Table 4. Among different crop sequences, groundnut–sesame was superior with a maximum index of 86.8% under INM, 73.1% under RDF and 46.0% under control. Groundnut–castor sequence was the 2nd best with a sustainable yield index of 52.4% under INM, 49.8% under RDF and 37.5% under control. Cotton–castor was the 3rd best with a sustainable yield index of 51.5% under INM, 40.7% under RDF, while groundnut–cotton was the 3rd best sequence under control.

Selection of the best crop sequence

Ranks were assigned to mean PEY (kg ha^{-1}), CV(%) of yield, yield increase (%) over control, prediction error (kg ha^{-1}) and sustainable yield index under each crop sequence(Table 5). Based on rank sum, under INM groundnut–sesame was highly efficient with lowest rank sum of 13, followed by cotton–castor with 18. Cotton–castor was superior under RDF with lowest rank sum of 19, while groundnut–castor was superior under control with lowest rank sum of 9 based on the study. Groundnut–sesame was the 2nd best sequence with a rank sum of 20 under RDF and 14 under control. Based on the ranks assigned to crop sequences under INM, RDF and control, the crops performed relatively better with INM compared to RDF and control.

CONCLUSION

Groundnut–sesame sequence was found to be the best with a significantly higher pod equivalent yield, minimum rank sum for mean, C.V., yield increase over control, prediction error and sustainable yield index among 12 crop sequences. Application of fertilizer through INM was superior as compared to RDF and control for different crop sequences. INM treatment has significant effect on yield with July and August rainfall as compared to RDF and control.

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