Journal of Agrometeorology 11 (1): 67-72 (June 2009)

Optimum fertilizer in relation to seasonal rainfall in pearl millet and groundnut crops in semi-arid vertisol of Rajkot (Gujarat, India) region

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ABSTRACT

A field experiment was conducted to select a sustainable treatment and optimize N in relation to seasonal rainfall for attaining maximum and economic yield of pearlmillet in a semi-arid *Vertisol* (Rajkot, Gujarat state, India). The treatments were different combinations of urea, green leaf and compost Crops was raised in eight seasons with permanent and rotation strip .Based on regression analysis, fertilizer N dose of 38 and 44 kg ha^{-1} at crop seasonal rainfall of 250 mm; 55 and 64 kg ha^{-1} at 500 mm; and 73 and 84 kg ha^{-1} at 750 mm was found to be optimum for targeting maximum yield of pearlmillet under permanent and rotation strips, respectively. Similarly, a dose of 25 and 29 kg ha^{-1} at 250 mm; 42 and 49 kg ha^{-1} at 500 mm; and 60 and 69 kg ha^{-1} a at 750 mm rainfall was optimum for attaining economic yield of pearlmillet under permanent and rotation strips, respectively in a semi-arid condition. Similar results were obtained with groundnut crop.

Key words : Optimum rainfall, fertilizer application, economic yield, pearlmillet, groundnut

Among different inputs, distribution of crop seasonal rainfall would influence rainfed groundnut and pearlmillet productivity to a large extent. Apart from rainfall, judicial use of N fertilizer is essential to attain a sustainable crop yield under rainfed conditions. Optimizing fertilizers for rainfed crops was reported by different workers. Mathur (1997) and Ram (1998) described strategies for rationalizing fertilizer application in relation to seasonal rainfall and soil fertility. Vittal *et al.,* (2004) described district-wise promising technologies for rainfed groundnut in different agro-eco sub-regions in India under semi-arid vertisol.

Regression models are useful for quantifying the effect of rainfall and fertilizer on yield and derive precise optimum fertilizer doses (Draper and Smith, 1998; Maruthi Sankar *et al.,* 2001). The fertilizer treatments can be assessed based on a sustainable yield index of crops and a superior treatment can be selected for large scale adoption (Vittal *et al.,* 2002 and 2003). An attempt is made in this paper to optimize fertilizer N at varying levels of crop seasonal rainfall for attaining maximum and economic yield of pearlmillet and residual effect on groundnut in a semi-arid Vertisol.

MATERIALS AND METHODS

Field experiments were conducted on pearlmillet (*Pennisetum americanum* L.) and groundnut (*Arachis hypogea* L.) under permanent and rotation strips for each crop during eight rainy seasons from 1998 to 2005 in a semi-arid vertisol at Dry Farming Research Station, Junagadh Agricultural University, Targhadia. The research center is located at a latitude of 20° 17' N, longitude of 70° 48' E and altitude of 137.7 m above mean sea level. The study was conducted with the objectives of assessing the performance of 9 organic and inorganic fertilizer N treatments on the productivity of pearlmillet and groundnut at varying crop seasonal rainfall and precisely optimize N for attaining sustainable maximum and economic yield of crops. The dates of sowing and harvest of pearlmillet and groundnut, along with crop growing period and crop seasonal rainfall received during June–September in different years are given in Table 1. The crop duration varied mainly because of distribution of rainfall and withdrawal of monsoon. It varied between 78 days (2003) and 92 days (2002) for pearlmillet and between 78 days (1999) and 121 days (1998) for groundnut.

The crop seasonal rainfall that occurred during eight years was in a range of 211 mm (18 rainy days) in 1999 to 1041 mm (33 rainy days) in 2005 with variation of 51%. The crop seasonal rainfall (%) to total rainfall ranged from 63% in 1999 to 99% in 2001, 2002 and 2003 with a variation of 19%. The rainfall ranged from 5.1 mm in 2000 to 270.5 mm in 2005 in June; 4.8 mm in 2002 to 356.9 mm in 2003 in July; 12.7 in 1999 to 318.8 mm in 2004 in August; and 'no rainfall' in 2004 to 348 mm in 2005 in September in different seasons.

Organic and inorganic fertilizer combinations

A fertilizer dose of 80 kg ha^{-1} of N and 40 kg ha^{-1} of P for pearlmillet and 12.5 kg ha^{-1} of N and 25 kg ha^{-1} of P for groundnut are being used as a general recommended dose in Gujarat. With the objective of identifying an efficient and cost effective combination of N through organic and inorganic

sources that would provide a sustainable crop yield under the different rainfall conditions, 9 combinations of N sources were tested under permanent and rotation strips for pearlmillet and their residual effect on groundnut in 8 seasons. The fertilizer N treatments tested are as under

The trials were conducted in a Randomized Block Design with 3 replications. Recommended agronomic practices were adopted while conducting the experiment.

Methodology for treatment evaluation

The treatment differences of organic and inorganic fertilizers were tested based on the standard Analysis of Variance procedure. The treatments were tested for superiority by comparing the observed yield differences with a critical difference at 5 and 1% level of significance and were ranked over seasons. The effect of crop seasonal rainfall on yield was assessed by calibrating separate regression models of yield attained under permanent and rotation strips as a function of linear and quadratic variables of crop seasonal rainfall received during June to September as

$$Y = \pm \alpha \pm \beta1 (RF\ Jun) \pm \beta2 (RF^2\ Jun) \pm \beta3 (RF\ Jul) \pm \beta4 (RF^2\ Jul) \pm \beta5 (RF\ Aug) \pm \beta6 (RF^2\ Aug) \pm \beta7 (RF\ Sep) \pm \beta8 (RF^2\ Sep) \quad \ldots\ldots\ldots (1)$$

The effect of monthly rainfall on yield was assessed based on the coefficient of determination (R^2), prediction error (Φ) based on a model and regression coefficients $\beta1$ to $\beta8$ of rainfall received in different months during 8 years. The coefficient of determination of model (Eq. 1) was tested using F-test (Draper and Smith, 1998).

Optimization of fertilizer N

Using pooled data of yield attained with 9 fertilizer treatments over 8 years, a regression model of yield as a function of linear and quadratic variables of organic and inorganic fertilizer N, crop seasonal rainfall, crop duration and interaction of fertilizer N with crop seasonal rainfall can be given as

$$Y = \pm á \pm \beta1 (FN) \pm \beta2 (FN)^2 \pm \beta3 (ON) \pm \beta4 (ON)^2 \pm \beta5 (CRF) \pm \beta6 (CRF)^2 \pm \beta7 (CGP) \pm \beta8 (CGP)^2 \pm \beta9 (FN) (CRF) \pm \beta10 (ON) (CRF) \quad \ldots\ldots. (2)$$

In (2), á is intercept and $\beta1$ to $\beta10$ are regression coefficients of inorganic and organic fertilizer N and crop seasonal rainfall variables. The superiority of a fertilizer treatment could be assessed based on a sustainable yield index 'η' discussed by Vittal *et al.*, (2002 and 2003). The η was derived for pearlmillet and groundnut separately under permanent and rotation strips.

Using mean yield of a treatment 'i' ($\hat{A}_i$) over eight years and prediction error (Ö) based on model (2); the sustainable yield index of a treatment 'i' is derived with reference to taking maximum yield (Y_{max}) attained with any fertilizer treatment in the study period, as the base

$$\eta_i = [(\hat{A}_i - Ö) / (Y_{max})] * 100 \quad \ldots\ldots\ldots\ldots (3)$$

A treatment with maximum η is selected for identifying a sustainable crop yield under permanent and rotation strips at different crop seasonal rainfall situations. The optimal fertilizer doses could be derived following Maruthi Sankar *et al.*, (2001) to plan for maximum and economic yield of pearlmillet.

RESULTS AND DISCUSSION

Pearlmillet yield

The fertilizer treatments were found to be significantly different from each other for their effect on pearlmillet yield (Table 2). The minimum and maximum mean yield of pearlmillet were provided by control and 80 kg N ha^{-1}, respectively under both permanent and rotation strips over eight seasons. Under permanent strip, the mean yield ranged from 1.091 t ha^{-1} with a variation of 40.6% to 1.838 t ha^{-1} with a variation of 35.8%, while it ranged from 1.318 t ha^{-1} with a variation of 31.3% to 1.903 t ha^{-1} with a variation of 29.1% under rotation strip.

Application of 80 kg N ha^{-1} was found significantly superior with a maximum yield increase of 68.5%, while 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) gave lowest yield increase of 18.5% over control in the permanent strip. Similarly, 80 kg N ha^{-1} gave maximum yield increase of 44.4%, while 15 kg N (compost) + 10 kg N ha^{-1} (green leaf) gave lowest increase of 9.4% in the rotation strip. Between the two strips, the treatments showed maximum mean yield increase of 36.6% in permanent strip compared to 19.5% in rotation strip over control.

Groundnut pod yield

Based on analysis of variance, the fertilizer treatments differed significantly for their residual effect on groundnut pod yield (Table 3). Application of 25 kg N ha^{-1} (compost) was found superior with significantly higher residual effect as compared to control and gave a maximum of 1224 kg ha^{-1} with a variation of 49% under permanent strip, The control gave a minimum pod yield of 1015 kg ha^{-1} with variation of 57.1% compared to a maximum of 1396 kg ha^{-1} with variation of 44% in 80 kg N (urea) under rotation strip.

Depleted pod yields with a negative residual effect of

Table 1: Date of sowing and harvest of pearlmillet and groundnut and rainfall received during crop season

Year	Date of sowing	Date of harvest	Crop duration PM(GN)	Rainfall (mm) received in				CRF (% of ARF)
				Jun	Jul	Aug	Sep	
1998	2-Jul	30-Sep (17-Nov)	90 (121)	144.8	103.3	185.6	148.7	582 (72)
1999	23-Jun	17-Sep (9-Sep)	85 (78)	56.9	97.7	12.7	43.6	211 (63)
2000	5-Jul	20-Sep (17-Oct)	86 (102)	5.1	273.5	74.5	13.4	367 (98)
2001	19-Jun	19-Sep (3-Oct)	82 (105)	71.9	216.0	115.8	19.8	424 (99)
2002	2-Jul	3-Oct (9-Oct)	92 (98)	207.5	4.8	91.0	6.1	309 (99)
2003	20-Jun	10-Sep (30-Sep)	78 (101)	211.8	356.9	222.7	11.8	803 (99)
2004	17-Jun	14-Sep (14-Oct)	89 (119)	40.4	289.7	318.8	0.0	649 (67)
2005	24-Jun	20-Sep (5-Oct)	88 (103)	270.5	227.5	194.6	348.0	1041 (91)
Mean			86 (103)	126.1	196.2	152.0	73.9	548 (86)
CV			5 (13)	76	60	64	163	51 (19)

CV: Coefficient of variation (%) PM: Pearl millet GN: Groundnut
CRF : Crop seasonal rainfall (mm) ARF : Annual rainfall (mm)

Table 2: Effect of N fertilizer on pearlmillet yield (t ha^{-1})

Treatment	Permanent strip			Rotation strip		
	Mean	CV %	Increase (%)	Mean	CV %	Increase (%)
Control	1091	40.6		1318	31.3	
80 kg N ha^{-1} (urea)	1838	35.8	68.5	1903	29.1	44.4
40 kg N ha^{-1} (urea)	1428	33.6	30.8	1488	34.0	12.9
25 kg N ha^{-1} (compost)	1643	32.8	50.6	1544	28.5	17.2
15 kg N (compost) + 10 kg N ha^{-1} (urea)	1484	25.4	36.0	1534	27.2	16.4
15 kg N (compost) + 20 kg N ha^{-1} (urea)	1511	27.9	38.5	1582	29.2	20.0
15 kg N (green leaf) + 10 kg N ha^{-1} (urea)	1393	43.6	27.7	1455	32.5	10.4
15 kg N (green leaf) + 20 kg N ha^{-1} (urea)	1336	32.2	22.4	1649	26.6	25.1
15 kg N (compost)+ 10 kg N ha^{-1} (green leaf)	1293	29.4	18.5	1442	30.5	9.4
Mean	1446	33.3	36.6	1546	29.8	19.5
SEm ±	91			51		
Critical difference (5%)	253			140		

CV : Coefficient of variation (%)

fertilizer were observed in permanent strip compared to rotation strip(Table 3). A mean groundnut pod yield of 1234 kg ha^{-1} with a yield increase of 24.3% was attained in rotation strip compared to a mean yield of 1065 kg ha^{-1} and yield increase of 7.4% in permanent strip.

Effect of crop seasonal rainfall on yield of pearlmillet

The pearlmillet yield attained under permanent and rotation strips had a significant negative correlation with rainfall received in June (-0.52** and –0.60**) and positive correlation with rainfall received in July (0.24* and 0.62**), while it was not significantly correlated with rainfall of August and September under both situations.

The regression models for yield calibrated as a function of linear and quadratic effects of rainfall received in different months are given in Table 4. The regression model for permanent strip gave a predictability of 0.64** with prediction error of 318 kg ha^{-1} while, for rotation strip these values were 0.82** and 209 kg ha^{-1}, respectively. The models indicated that the rainfall received in July, August and September had a positive influence, while June rainfall had a negative influence on yield.

Effect of crop seasonal rainfall on groundnut pod yield

The pod yield had a significant positive correlation with crop seasonal rainfall in permanent (0.38**) and rotation (0.53**) strips. It had a significant positive correlation with July rainfall in permanent and rotation strips, with June and September rainfall under rotation strip. It increased significantly over years in rotation (0.25*) strip, while it was not significant in permanent strip.

The regression model of yield (Table 4) of permanent

Table 3: Residual effect of N fertilizer on groundnut pod yield (t ha^{-1})

Treatment	Permanent strip			Rotation strip		
	Mean	CV %	Increase (%)	Mean	CV%	Increase (%)
Control	999	56.4		1015	57.1	
80 kg N ha^{-1} (urea)	1121	35.1	12.2	1396	44.0	37.6
40 kg N ha^{-1} (urea)	1042	44.8	4.3	1172	47.6	15.5
25 kg N ha^{-1} (compost)	1224	49.0	22.5	1366	55.4	34.5
15 kg N (compost) + 10 kg N ha^{-1} (urea)	1030	42.7	3.1	1382	53.6	36.2
15 kg N (compost) + 20 kg N ha^{-1} (urea)	1159	42.3	16.0	1272	56.6	25.3
15 kg N (green leaf) + 10 kg N ha^{-1} (urea)	924	43.2	-7.5	1173	42.3	15.6
15 kg N (green leaf) + 20 kg N ha^{-1} (urea)	1088	44.6	8.9	1196	40.4	17.8
15 kg N (compost)+ 10 kg N ha^{-1} (green leaf)	999	50.3	0.0	1134	53.4	11.7
Mean	1065	45.3	7.4	1234	50.0	24.3
Sem ±	59			81		
Critical difference (5%)	167			227		

CV : Coefficient of variation (%)

Table 4: Regression models for predicting yield of pearlmillet and groundnut through monthly rainfall

Strip	Regression model	R^2	Φ
Pearlmillet grain yield			
Permanent	Y = 1752 ** – 18.79 ** (Jun RF) + 0.06 ** (Jun RF^2) + 8.13 ** (Jul RF) – 0.02 ** (Jul RF^2) + 1.23 (Aug RF) – 0.002 (Aug RF^2) + 15.28 ** (Sep RF) – 0.05 ** (Sep RF^2)	0.64**	318
Rotation	Y = 1413 ** – 8.99 ** (Jun RF) + 0.024 * (Jun RF^2) + 8.65 ** (Jul RF) – 0.017 ** (Jul RF^2) + 0.68 (Aug RF) – 0.004 (Aug RF^2) + 7.59 ** (Sep RF) – 0.02 ** (Sep RF^2)	0.82**	209
Groundnut pod yield			
Permanent	Y = -1570 ** + 8.99 ** (Jun RF) – 0.013 (Jun RF^2) + 25.87 ** (Jul RF) – 0.06 ** (Jul RF^2) – 1.45 * (Aug RF) – 0.001 (Aug RF^2) + 0.17 (Sep RF) – 0.02 ** (Sep RF^2)	0.89**	160
Rotation	Y = -2165 ** + 12.04 ** (Jun RF) – 0.011 (Jun RF^2) + 32.07 ** (Jul RF) – 0.08 ** (Jul RF^2) – 1.24 (Aug RF) + 0.001 (Aug RF^2) + 0.72 (Sep RF) – 0.02 ** (Sep RF^2)	0.87**	220

* & ** indicate significance at 5 & 1% level
Φ : Prediction error (kg ha^{-1})
RF : Rainfall (mm)
R^2 : Coefficient of determination

strip had a maximum and significant predictability of 0.89** with prediction error of 160 kg ha^{-1}, while the model of rotation strip had a significant predictability of 0.87** with prediction error of 220 kg ha^{-1}. It is observed that June, July and September rainfall had a positive effect, while August rainfall had a negative effect on pod yield. Rainfall received in June and July had a significant effect on yield attained in permanent and rotation strips, while August rainfall had a significant effect on yield of permanent strip.

Prediction of crop yield through growing period, seasonal rainfall and N fertilization

The estimates of regression coefficients of different variables and their significances, coefficient of determination and prediction error in permanent and rotation strips using calibrated models are given in Table 5. In pearlmillet, the model for rotation strip gave a maximum predictability of 0.74** compared to permanent strip with 0.54**. A lower prediction error of 254 kg ha^{-1} was observed in rotation strip compared to 371 kg ha^{-1} in permanent strip based on the model. Both linear and quadratic regression coefficients of growing period and seasonal rainfall indicate a significant influence of rainfall on yield of both crops in permanent and rotation strips; pearlmillet yield could be better predicted with a lower prediction error in rotation strip, while groundnut pod yield could be better predicted with lower prediction error in permanent strip.

Table 5: Regression models for predicting yield of pearlmillet and groundnut through growing period, seasonal rainfall and N fertilizer

Strip	Regression model	R^2	Φ
Pearlmillet grain yield			
Permanent	$Y = -118945$ ** $+ 2.74$ (FN) $- 0.07$ (FN^2) $- 1.34$ (ON) $+ 0.16$ (ON^2) $+ 4.44$ ** (CRF) $- 0.01$ ** (CRF^2) $+ 2800.9$ ** (CGP) $-$ 16.44 ** (CGP^2) $+ 0.01$ (FN) (CRF) $+ 0.02$ (ON) (CRF)	0.54**	371
Rotation	$Y = -116137$ ** $+ 2.9$ (FN) $+ 0.06$ (FN^2) $+ 8.16$ (ON) $- 0.20$ (ON^2) $+ 4.76$ ** (CRF) $- 0.01$ ** (CRF^2) $+ 2773.5$ ** (CGP) $-$ 16.5 ** (CGP^2) $+ 0.01$ (FN) (CRF) $+ 0.01$ (ON) (CRF)	0.74**	254
Groundnut pod yield			
Permanent	$Y = -105281$ ** $+ 1.91$ (FN) $- 0.12$ (FN^2) $+ 43.13$ (ON) $-$ 1.57 (ON^2) $+ 6.16$ ** (CRF) $- 0.005$ ** (CRF^2) $+ 1944.1$ ** (CGP) $- 8.99$ ** (CGP^2) $+ 0.01$ (FN) (CRF) $+ 0.02$ (ON) (CRF)	0.83**	208
Rotation	$Y = -114697$ ** $+ 31.61$ (FN) $- 0.67$ (FN^2) $+ 41.19$ (ON) $-$ 1.24 (ON^2) $+ 6.28$ ** (CRF) $- 0.004$ ** (CRF^2) $+ 2218.8$ ** (CGP) $- 9.81$ ** (CGP^2) $+ 0.01$ (FN) (CRF) $+ 0.029$ (ON) (CRF)	0.75**	328

* & ** indicate significance at 5 & 1% level
FN : Fertilizer N (kg ha^{-1})
CGP : Crop growing period
R^2: Coefficient of determination
CRF : Crop seasonal rainfall (mm)
ON : Organic N (kg ha^{-1})
Φ : Prediction error (kg ha^{-1})

Table 6: Optimum fertilizer N at varying crop seasonal rainfall

Strip	Fertilizer N equation	Fertilizer N at varying rainfall (mm)					
		Maximum yield			Economic yield		
Pearlmillet		250	500	750	250	500	750
Permanent	FN = 20 + 0.07 (CRF) – 7.14 (Z)	38	55	73	25	42	60
Rotation	FN = 24 + 0.08 (CRF) – 8.33 (Z)	44	64	84	29	49	69
Groundnut							
Permanent	FN = 8 + 0.04 (CRF) – 4.17 (Z)	18	28	38	16	26	36
Rotation	FN = 24 + 0.007 (CRF)–0.75 (Z)	26	28	29	25	27	29

Cost of fertilizer N : Rs.10.8/kg
Value of groundnut : Rs.25/kg
Value of pearlmillet : Rs.6/kg
Z = (Cost of fertilizer) / (Value of the crop)

The sustainability yield index (SYI) of each fertilizer treatment (Fig.1) was derived based on equation (3) using mean yield attained over 8 years, prediction error based on a regression model and maximum yield of a crop attained in either permanent or rotation strip. It is observed that application of 80 kg N ha^{-1} was superior with a maximum SYI of 77.0 and 75.0% for pearlmillet yield in permanent and rotation strips respectively. In groundnut, residual effect of 80 kg N ha^{-1} was superior with a maximum SYI of 87.0% in rotation strip, while 25 kg N ha^{-1} (compost) was superior with a maximum SYI of 72.0% in permanent strip.

Optimization of fertilizer N for seasonal rainfall

Based on regression models (Table 5) adjustment equations were derived for optimizing N at different crop seasonal rainfall levels of 250, 500 and 750 mm for attaining maximum and economic yield of crops (Table 6). A price of Rs.10.8 kg^{-1} of fertilizer N, Rs.6/kg of pearlmillet grain and Rs.25 kg^{-1} of groundnut pod were used.

Optimum N for maximum yield of pearlmillet was found to be 38 and 44 kg ha^{-1} at 250 mm; 55 and 64 kg ha^{-1} at 500 mm; and 73 and 84 kg ha^{-1} at 750 mm of crop seasonal rainfall in permanent and rotation strips respectively. Similarly, a dose of 25 and 29 kg ha^{-1} at 250 mm; 42 and 49 kg ha^{-1} at 500 mm; and 60 and 69 kg ha^{-1} at 750 mm rainfall was found optimum for attaining economic yield of pearlmillet in the two respective strips. In case of groundnut, the residual effect of 18 and 26 kg ha^{-1} at 250 mm; 28 kg ha^{-1} each at 500 mm; and 38 and 29 kg ha^{-1} at 750 mm was optimum for maximum pod yield in permanent and rotation

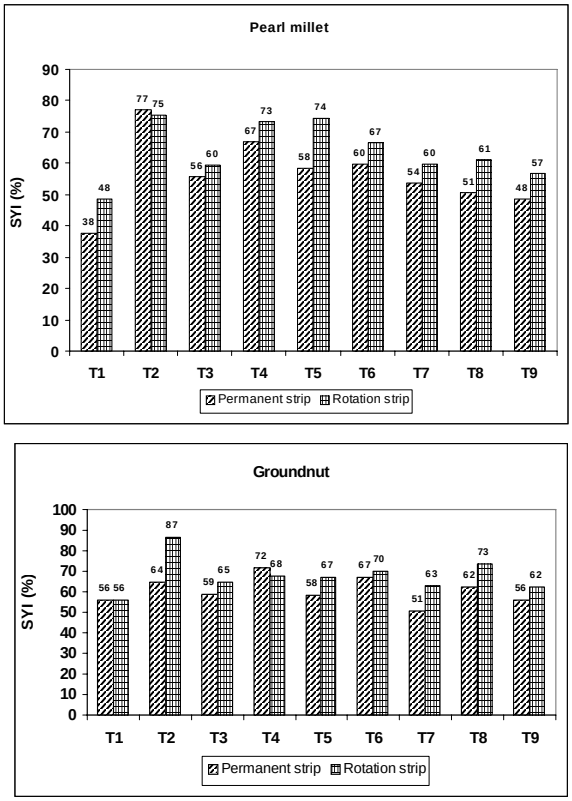

Fig.1: Sustainable yield index of fertilizer treatments for pearlmillet and groundnut at Targhadia (Rajkot)

strips respectively. Similarly, the residual effect of 16 and 25 kg ha^{-1} at 250 mm; 26 and 27 kg ha^{-1} at 500 mm; and 36 and 29 kg ha^{-1} at 750 mm rainfall was optimum for attaining economic yield in the two respective strips based on the study.

The optimum N dose for maximum and economic yield of pearlmillet was relatively higher under rotation compared to permanent strip at different crop seasonal rainfall. In case of groundnut, the N dose was higher under rotation strip at a rainfall of 250 mm, while it was higher under permanent strip at a rainfall of 750 mm and an equal dose at 500 mm. The optimum N was meaningful and within the range of fertilizer levels tested. The study indicated that out of optimum N dose, 50% may be applied through organic source and the remaining through inorganic fertilizer for attaining a sustainable yield of pearl millet and groundnut under rotation system in semi-arid vertisols.

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Received : October 2008; Accepted : March 2009