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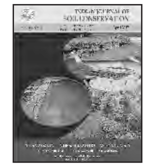

Efficient tillage and nitrogen practices for improving monetary returns and yield of finger millet and pigeonpea in semi-arid Alfisols

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ABSTRACT

Field experiments were conducted with three tillage treatments *viz.,* CT: Conventional tillage (3 ploughings + 3 intercultures), RT: Reduced tillage (2 ploughings + 2 intercultures) and MT: Minimum tillage (one ploughing + one interculture) in combination with three nitrogen levels *viz.,* F1: 100% N (organic), F2: 50% N (organic) + 50% N (inorganic) and F3: 100% N (inorganic) to identify the best management practices for improving soil fertility and sustain yield of finger millet (*Eleusine coracana*) and pigeonpea (*Cajanus cajan*) under semi-arid Alfisols during 2003 to 2011. The results revealed that CTF2 gave significantly higher mean finger millet yield of 2613 kg ha^{-1} and rainwater use efficiency (RWUE) of 4.48 kg ha^{-1} mm^{-1}, while CTF1 gave significantly higher pigeonpea yield of 907 kg ha^{-1} and RWUE of 4.10 kg ha^{-1} mm^{-1} over years. Further, CTF2 gave maximum net returns of ₹ 31639 ha^{-1} and benefit-cost (B:C) ratio of 3.65 with sustainability yield index (SYI) of 59.0% from finger millet, while CTF1 gave net returns of ₹ 43801 ha^{-1} and B:C ratio of 3.26 with SYI of 56.6% from pigeonpea. Based on the effects of tillage and nitrogen on soil parameters observed in 2003 and 2011, there was a decrease in the pH, soil P and organic carbon, while there was an increase in the electrical conductivity, soil N and K. Application of N through organics or as combination of organics and inorganics, maintained maximum soil fertility compared to inorganic N alone. We conclude that CT + 50% N (organic) + 50% N (inorganic) for finger millet and CT + 100% N (organic) for pigeonpea under rotation are efficient for attaining maximum yield, RWUE, monetary returns and SYI in semi-arid Alfisols.

1. INTRODUCTION

Rainfed agriculture plays a vital role in contributing to world food security. In India, about 85 million ha (m ha) area is under rainfed agriculture which represents 60% of net cultivated area and supports 40% population of the country. Apart from climatic constraints of erratic and uncertain rainfall, the soils are highly degraded physically, chemically and biologically (Vittal *et al.,* 2003; Sharma *et al.,* 2005; Maruthi Sankar *et al.,* 2006). The intensive tillage practices employing inversion implements like mould-board and chiesel plough would result in loss of soil organic carbon (SOC) from soil aggregates. Moreover, continuous imbalanced fertilization and no recycling of crop residues led to deterioration of soil quality, which results in low crop productivity in the rainfed regions (Campbell *et al.,* 2001; Roldan *et al.*, 2003; Sharma *et al.*, 2008b). Lal (2007) reported that the benefits of zero till farming in combination with residue retention are substantial for erosion control, water conservation, soil fertility enhancement and carbon sequestration. After harvest, the farmers remove crop residue from soil surface for feeding livestock and using it as fuel for domestic cooking. Due to moisture scarcity, there is little scope to grow green manure and biomass generating field crops without incurring loss on account of losing the crop season. Consequently, except the inadvertent retention of root biomass below ground, low amount of residue is recycled back to agricultural fields.

Sharma *et al.* (2005) reported that minimum tillage in combination with 90 kg N ha^{-1} in castor-sorghum system, maintained desirable soil quality index of 1.1 in rainfed Alfisols. Further, they reported that primary tillage along with organic residues and N application are crucial to maintain higher yield as well as soil quality. Elimination of summer fallowing in arid and semi-arid regions and adopting no tillage (NT) with residue mulch improved the soil structure, reduced bulk density, increased infiltration rate and productivity (Lal, 2004; Shaver *et al.,* 2002). Minimum tillage would maintain lower temperature, water, oxygen and thereby induce suitable environment for growth and activity of microflora and microfauna (Blevins and Frye, 1993; Follet, 1990). Camara *et al.* (2003) studied long-term effects of tillage, nitrogen and rainfall on wheat yield and found that despite beneficial effects on soil properties, conservation tillage tended to be less productive than ploughing with mould-board plough due to poor control of downy brome weed control under low tillage. Peeyush Sharma *et al.* (2011) described that minimum tillage in combination with mulches had a pronounced effect on the soil physical properties, productivity, energy requirement, monetary returns of maize-wheat system in a sub-humid Inceptisol. Videnovic *et al.* (2011) attained significantly higher maize yield with CT compared to reduced tillage and NT, irrespective of fertilizer application in a Chernozem soil. Though much efforts have gone into such studies in the temperate regions, systematic studies are rare in semi-arid tropical regions. This is because of difficulties in controlling weeds, less water infiltration in a compacted soil and non-availability of appropriate seeding implements (Sharma *et al.,* 2008b).

Finger millet is an important crop of tropical and sub-tropical countries. It is a staple food for working class and also an ideal food for patients suffering from diabetes. The grains are rich in calcium and iron besides being rich in carbohydrate and protein. In India, finger millet was grown in an area of 13.81 lakh ha and attained production of 20.4 lakh tons with productivity of 1477 kg ha^{-1} during 2008. Pigeonpea is one of the important pulses rich in protein content. Being a legume, the crop would fix atmospheric N and shed lot of leaves at maturity which would improve the organic matter content of a soil. Under rainfed conditions in south India, finger millet-pigeonpea rotation is predominantly followed experiencing moisture deficiency at different growth stages. There is an urgent need to improve the finger millet productivity to make the system more profitable with efficient tillage and nutrient practices. Thus, the present study was conducted to identify an efficient tillage and nitrogen practice which would improve the soil fertility, and provide maximum sustainable yield, monetary returns and RWUE from finger millet-pigeonpea rotation under semi-arid Alfisols.

2. MATERIALS AND METHODS

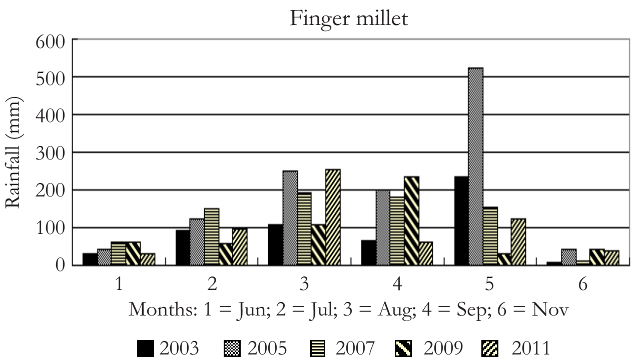
Experimental Details

Field experiments were conducted in the same site for nine consecutive years with finger millet (*Eleusine coracana*) and pigeonpea (*Cajanus cajan*) in the alternate years under rotation at University of Agricultural Sciences, Bangalore under semi-arid Alfisols during 2003 to 2011. Bangalore is located in the agro-climatic zone V (Eastern Dry Zone) of Karnataka at a latitude of 12°58' North, longitude of 77°35' East and an altitude of 930 m above msl. The experiments were conducted in a split-plot design with three replications. The treatments were randomized and superimposed to the plots in the first year and continued every year in the same plots in the subsequent years. The three tillage treatments as main plot *viz.,* (i) CT: Conventional tillage; (ii) RT: Reduced tillage; and (iii) MT: Minimum tillage; while the nitrogen levels as subplot *viz.,* (i) F1: 100% N (organic), (ii) F2: 50% N(organic) + 50% N (inorganic) and (iii) F3: 100% N (inorganic) were superimposed. CT comprised of 3 ploughings + 3 intercultures; while RT comprised of 2 ploughings + 2 intercultures and MT comprised of one ploughing + one interculture. Farmyard manure (FYM) and leaves of glyricidia (*Glyricidia maculata)*, a N fixing shrub containing 3% N in leaves on dry weight basis) were used as organic sources. Seed rate @ 12 kg ha^{-1} for finger millet and 15 kg ha^{-1} for pigeonpea were used. Row x plant spacing of 30 x 10 cm for finger millet and 90 x 30 cm for pigeonpea were maintained. The recommended dose of N @ 50 kg ha^{-1}, P @ 40 kg ha^{-1} and K @ 25 kg ha^{-1} was applied as basal. Standard crop management practices were adopted for the two crops from sowing to harvest as described by Vittal *et al.* (2002). Soil samples from a depth of 0-30 cm were collected from each experimental plot in 2003 and 2011 and analyzed for soil pH and electrical conductivity (Rhoades, 1982), SOC (Walkley and Black, 1934), available N (Subbaiah and Asija, 1956), available P (Olsen *et al.,* 1954) and available K (Hanway and Heidel, 1952).

Distribution of Rainfall in Different Years

Finger millet received rainfall of 525 to 1175 mm, while pigeonpea received 464 to 803 mm in the years in which the crops were grown under rotation. In the years when finger millet was grown, October received maximum mean rainfall of 212 mm, followed by August (181 mm), September (147 mm), July (103 mm), June (44 mm) and November (28 mm) over 5 years. In case of pigeonpea, September received maximum mean rainfall of 142 mm, followed by 138 mm each in July and October, 131 mm in August, 78 mm in June and 66 mm in November. The rainfall received in different months was erratic with minimum variation of 29.4% in July and maximum variation of 95.5% in November. The distribution of rainfall observed in finger millet and pigeonpea crops grown in alternate years during 2003 to 2011 is depicted in Fig.1.

In finger millet, the earliest date of sowing (DOS) was on 13th July in 2003, while the farthest was on 31st July in 2009.



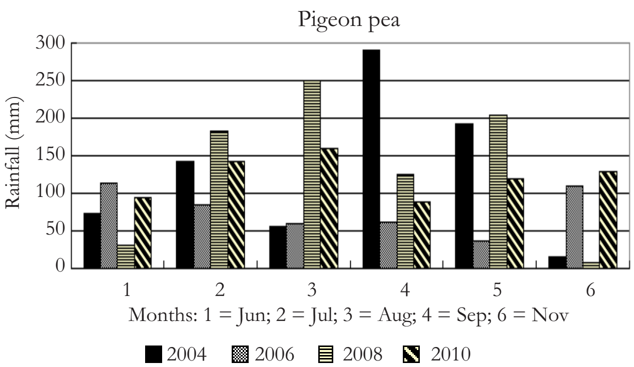


Fig. 1. Distribution of monthly rainfall in finger millet and pigeonpea grown in alternate years during 2003 to 2011

The earliest date of harvest (DOH) was on 10th November in 2007, while the farthest was on 11th December in 2009. In pigeonpea, the earliest DOS was on 24th May in 2010, while the farthest was on 28th June in 2004. The earliest DOH was on 28th November in 2006, while the farthest was on 10th January in 2004. The crop failed in 2008 due to delayed sowing in July, followed by erratic rainfall distribution. The crop growing period (CGP) of finger millet ranged from 116 to 143 days with mean duration of 128 days and variation of 9.2%, while pigeonpea had a CGP of 197 to 215 days with mean duration of 207 days and variation of 4.4%. The descriptive statistics of monthly rainfall received in different years along with DOS and DOH of finger millet and pigeonpea are given in Table 1.

Statistical Analysis

Based on the standard analysis of variance (ANOVA) of a split-plot design, the effects of tillage and N treatments in influencing the grain yield and RWUE of finger millet and pigeonpea were tested in individual years and also when pooled over years. The treatment differences were compared based on the least significant difference (LSD) criteria as described by Gomez and Gomez (1984). The RWUE (kg ha^{-1} mm^{-1}) attained by a treatment were expressed as a ratio of yield (kg ha^{-1}) and crop seasonal rainfall (CRF, mm) as described by Maruthi Sankar *et al.* (2012a) and Rockstrom *et al.* (2003). The effect of CRF on yield attained by treatments was assessed based on a linear regression model as follows:

$$Y = \pm \alpha \pm \beta 1(CRF) \pm \beta 2\,(CRF)^2 \qquad ...(1)$$

Where, α is intercept, β is slope of the rainfall effect on yield attained by a treatment and CRF is the crop seasonal rainfall (mm) from sowing to harvest. Since the rainfall is highly erratic and fluctuating, the treatments which maintained positive β values were considered superior from the

Table: 1
Monthly rainfall, date of sowing and harvest of finger millet and pigeonpea during 2003 to 2011

Year	DOS	DOH	CGP	June	July	Aug.	Sept.	Oct.	Nov.	Total
Finger millet										
2003	13-Jul	20-Nov	131	30	90	108	66	232	5	531
2005	18-Jul	7-Dec	143	40	122	249	198	524	41	1175
2007	28-Jul	10-Nov	116	60	149	190	179	152	12	742
2009	31-Jul	11-Dec	134	59	56	107	232	30	43	525
2011	22-Jul	24-Nov	116	30	96	253	60	123	38	599
Mean			128	44	103	181	147	212	28	714
CV			9.2	33.9	34.3	39.8	53.9	89.1	64.0	38.0
Pigeonpea										
2004	28-Jun	10-Jan	197	73	142	55	290	193	16	770
2006	21-Jun	28-Nov	215	113	84	60	61	36	110	464
2008	28-Jul	#	#	31	183	250	126	205	8	803
2010	24-May	17-Dec	208	95	142	159	89	119	129	733
Mean			207	78	138	131	142	138	66	693
CV			4.4	45.2	29.4	70.6	72.4	56.5	95.5	22.3

#Crop failed due to delayed sowing and erratic rainfall distribution; FM: Finger millet; PP: Pigeonpea; CGP: Crop growing period (days); DOS: Date of sowing; DOH : Date of harvest; CV : Coefficient of variation (%)

sustainability and efficient use of natural resources point of view. One of the criteria adopted to identify an efficient tillage treatment was SYI, which was derived as a "ratio of the difference of mean yield and prediction error based on the regression model and maximum yield attained by any treatment over years" as discussed by Behera *et al.* (2007), Maruthi Sankar *et al.* (2011, 2012a, 2012b) and Vittal *et al.* (2003).

In order to compute the profitability of tillage treatments over years, the gross and net returns and B:C ratio were derived as discussed by Maruthi Sankar *et al.* (2013) and Nema *et al.* (2008). The gross returns (₹ ha^{-1}) were computed as a product of mean yield attained by treatment over years and value of the crop, while the net returns (₹ ha^{-1}) was computed as a difference of gross returns and cost of cultivation (₹ ha^{-1}). The B:C ratio was derived as a ratio of gross returns and cost of cultivation for each treatment.

3. RESULTS AND DISCUSSION

Effect of Tillage and Nitrogen Treatments on Crop Yield

The nine tillage and nitrogen treatments gave mean finger millet yield of 2214 kg ha^{-1} with coefficient of variation of 23.1% over five years, while they gave mean pigeonpea yield of 727 kg ha^{-1} with variation of 31.4% over three years. Based on the analysis of variance of a split-plot design, the effects of tillage, nitrogen and their interaction were tested in each year and also when pooled over years (Table 2). The differences between tillage treatments in influencing the finger millet yield were significant ($p<0.05$) in all the five years for finger millet and three years for pigeonpea. However, the differences between N treatments were significant ($p<0.05$) in all the five years for finger millet, while they were significant only in two years (2004 and 2010) for pigeonpea. The interaction effect of tillage and N on yield was significant in finger millet during 2003, 2007, 2009 and 2011, while it was significant in pigeonpea only in 2010. Among treatment combinations of tillage and N, CTF2 attained maximum mean finger millet yield of 2613 kg ha^{-1}, while CTF1 attained maximum mean pigeonpea yield of 907 kg ha^{-1} over years in which the crops were grown in the study.

The differences between effects of tillage *viz.,* CT: Conventional tillage, RT: Reduced tillage and MT: Minimum tillage; and nitrogen *viz.,* F1: 100% N (organic), F2: 50% N (organic) + 50% N (inorganic) and F3: 100% N (inorganic) on finger millet and pigeonpea yield were compared based on Least Significant Difference criteria at $p<0.05$ level of significance. In finger millet, CT and RT were at par with each other and were superior over MT in 2003 and 2005; while CT was superior over RT and MT, and RT was superior over MT in 2007 and 2011 and when pooled over five years. In 2009, CT was superior over MT, while CT and RT, and RT and MT were at par with each other. Among N treatments, F2 was superior over F1 and F3, which were at par with each other in 2003. Similarly, F2 was superior over F1; while F2 and F3, and F1 and F3 were at par with each other in 2005. F2 was superior over F1 and F3; while F3 was superior over F1 in 2009 and when pooled over years.

In pigeonpea, CT and RT were at par with each other and were superior over MT in 2004 and also when pooled over three years. CT was superior over MT; while CT and RT, and RT and MT were at par with each other in 2006. Similarly, CT was superior over RT and MT, and RT was superior over MT in 2011. Among N treatments, F1 was superior over F2 and F3, which were at par with each other in 2004. Similarly, F1 was superior over F2 and F3, and F2 was superior over F3 in 2010 and when pooled over years. F1, F2 and F3 were at par with each other in 2006, while the crop failed in 2008 due to severe moisture stress based on erratic rainfall distribution.

Effect of Tillage and Nitrogen Treatments on RWUE

The treatment combinations gave mean RWUE of 3.75 kg ha^{-1} mm^{-1} with coefficient of variation of 23.1% in finger millet over five years, while they gave mean RWUE 3.90 kg $ha^{-1}mm^{-1}$ with variation of 31.4% in pigeonpea over three years (Table 3). Significant differences between tillage treatments in influencing RWUE were observed in all the five years for finger millet and three years for pigeonpea. However, differences between N treatments were significant in all the five years for finger millet, while they were significant in two years (2004 and 2010) in pigeonpea. Significant interaction effect of tillage and N on RWUE was observed in finger millet during 2003, 2007, 2009 and 2011, while it was significant in pigeonpea only in 2010. Among different treatment combinations of tillage and N, CTF2 gave maximum mean RWUE of 4.48 kg $ha^{-1}mm^{-1}$ in finger millet and 4.19 kg ha^{-1} mm^{-1} in pigeonpea over five and three years, respectively.

In finger millet, CT and RT were at par with each other and were superior over MT in 2003 and 2005. CT was superior over RT and MT, while RT was superior over MT in 2007, 2011 and when pooled over five years. In 2009, CT was superior over MT, while CT and RT, and RT and MT were at par with each other. Among N treatments, F2 was superior over F1 and F3, which were at par with each other in 2003 and 2011. Similarly, F2 was superior over F1; while F2 and F3, and F1 and F3 were at par with each other in 2005. F2 was superior over F1 and F3; while F3 was superior over F1 in 2007 and when pooled over three years. In 2009, F2 and F3 were at par with each other and were superior over F1.

In pigeonpea, CT was superior over MT; while CT and RT, and RT and MT were at par with each other in 2004. CT and RT were at par with each other and were superior over MT in 2006 and when pooled over years. CT was superior

Table: 2
Analysis of variance of tillage and fertilizer N treatments on yield of finger millet and pigeonpea

Year	Finger millet: Grain yield (kg ha^{-1})				Year	Pigeonpea: Grain yield (kg ha^{-1})			
Tillage (T)	Fertilizer (F)				Tillage (T)	Fertilizer (F)			
2003	F1	F2	F3	Mean	2004	F1	F2	F3	Mean
Conventional	2641	2845	2544	2677^{a}	Conventional	1055	1000	828	961^{a}
Reduced	2386	2842	2446	2558^{a}	Reduced	1038	851	776	888^{a}
Minimum	1564	2724	2092	2127^{b}	Minimum	604	553	517	558^{b}
Mean	2197^{b}	2804^{a}	2361^{b}	2454	Mean	899^{a}	801^{b}	707^{b}	802
LSD (T)	416				LSD (T)	259			
LSD (F)	277				LSD (F)	95			
LSD (TxF)	566				LSD (TxF)	NS			
2005					2006				
Conventional	3594	3667	3487	3583^{a}	Conventional	810	792	736	779^{a}
Reduced	3354	3487	3752	3531^{a}	Reduced	546	555	545	549^{ab}
Minimum	2739	3500	3153	3131^{b}	Minimum	376	351	277	335^{b}
Mean	3229^{b}	3551^{a}	3464^{ab}	3415	Mean	577	566	519	554
LSD (T)	286				LSD (T)	265			
LSD (F)	278				LSD (F)	NS			
LSD (TxF)	NS				LSD (TxF)	NS			
2007					2008				
Conventional	1012	1528	1300	1280^{a}	Conventional	#	#	#	
Reduced	916	1251	1053	1073^{b}	Reduced	#	#	#	
Minimum	541	1097	891	843^{c}	Minimum	#	#	#	
Mean	823^{c}	1292^{a}	1081^{b}	1065	Mean				
LSD (T)	172				LSD (T)				
LSD (F)	177				LSD (F)				
LSD (TxF)	302				LSD (TxF)				
2009					2010				
Conventional	1614	3208	2642	2488^{a}	Conventional	1530	996	548	1025^{a}
Reduced	1101	2843	2000	1981^{ab}	Reduced	1141	787	498	809^{b}
Minimum	820	2228	1557	1535^{b}	Minimum	924	577	426	642^{c}
Mean	1178^{c}	2760^{a}	2066^{b}	2001	Mean	1198^{a}	787^{b}	491^{c}	825
LSD (T)	560				LSD (T)	103			
LSD (F)	610				LSD (F)	59			
LSD (TxF)	176				LSD (TxF)	131			
2011									
Conventional	2447	3586	3058	3030^{a}					
Reduced	1664	3037	2068	2256^{b}					
Minimum	884	1376	1098	1119^{c}					
Mean	1665^{c}	2666^{a}	2075^{b}	2135					
LSD (T)	319								
LSD (F)	230								
LSD (TxF)	398								
Pooled over years	Pooled over years								
Conventional	2262	2967	2606	2611^{a}	Conventional	1132	929	704	922^{a}
Reduced	1884	2692	2264	2280^{b}	Reduced	908	731	606	749^{a}
Minimum	1310	2185	1758	1751^{c}	Minimum	635	494	407	512^{b}
Mean	1818^{c}	2615^{a}	2209^{b}	2234	Mean	892^{a}	718^{b}	572^{c}	727
LSD (T)	250				LSD (T)	209			
LSD (F)	205				LSD (F)	77			
LSD (TxF)	361				LSD (TxF)	131			

LSD : Least significant difference at $p < 0.05$ level; Treatments with same letter (a, b, c) are at par with each other; F1 : 100% N (organic); F2 : 50% N (organic) + 50% N (inorganic); F3 : 100% N (inorganic); #: Crop Failed

over RT and MT, and RT was superior over MT in 2010. Among N treatments, F2 was superior over F1 and F3, and F3 was superior over F1 in 2004. F1 was superior over F2 and F3, and F2 was superior over F3 in 2010. F1, F2 and F3 were at par with each other in 2006, while the crop failed in 2008 due to severe moisture stress based on erratic rainfall distribution.

Relationship Between Rainfall and Yield

In order to assess the effect of crop seasonal rainfall on

Table: 3
ANOVA of tillage and fertilizer N treatments on rainwater use efficiency in finger millet and pigeonpea

Year	Finger millet				Year	Pigeonpea			
Tillage (T)	Fertilizer (F)				Tillage (T)	Fertilizer (F)			
2003	F1	F2	F3	Mean	2004	F1	F2	F3	Mean
Conventional	6.29	6.77	6.06	6.37^{a}	Conventional	1.41	2.12	1.81	1.78^{a}
Reduced	5.68	6.77	5.82	6.09^{a}	Reduced	1.27	1.74	1.46	1.49^{ab}
Minimum	3.72	6.49	4.98	5.06^{b}	Minimum	0.75	1.52	1.24	1.17^{b}
Mean	5.23^{b}	6.68^{a}	5.62^{b}	5.84	Mean	1.14^{c}	1.79^{a}	1.50^{b}	1.48
LSD (T)	0.99				LSD (T)	0.36			
LSD (F)	0.66				LSD (F)	0.13			
LSD (TxF)	1.35				LSD (TxF)	NS			
2005					2006				
Conventional	3.43	3.50	3.32	3.42^{a}	Conventional	8.85	9.03	8.59	8.82^{a}
Reduced	3.20	3.32	3.58	3.37^{a}	Reduced	8.26	8.59	9.24	8.70^{a}
Minimum	2.61	3.34	3.01	2.99^{b}	Minimum	6.75	8.62	7.77	7.71^{b}
Mean	3.08^{b}	3.39^{a}	3.30^{ab}	3.26	Mean	7.95	8.75	8.53	8.41
LSD (T)	0.27				LSD (T)	0.65			
LSD (F)	0.27				LSD (F)	NS			
LSD (TxF)	NS				LSD (TxF)	NS			
2007					2008				
Conventional	2.20	3.33	2.83	2.79^{a}	Conventional	#	#	#	
Reduced	2.00	2.73	2.29	2.34^{b}	Reduced	#	#	#	
Minimum	1.18	2.39	1.94	1.84^{c}	Minimum	#	#	#	
Mean	1.79^{c}	2.82^{a}	2.35^{b}	2.32	Mean				
LSD (T)	0.37				LSD (T)				
LSD (F)	0.39				LSD (F)				
LSD (TxF)	0.66				LSD (TxF)				
2009					2010				
Conventional	3.56	7.07	5.82	5.48^{a}	Conventional	3.37	2.19	1.21	2.26^{a}
Reduced	2.43	6.26	4.41	4.37^{ab}	Reduced	2.51	1.73	1.10	1.78^{b}
Minimum	1.81	4.91	3.43	3.38^{b}	Minimum	2.04	1.27	0.94	1.42^{c}
Mean	2.60^{b}	6.08^{a}	4.55^{a}	4.41	Mean	2.64^{a}	1.73^{b}	1.08^{c}	1.82
LSD (T)	1.20				LSD (T)	0.23			
LSD (F)	1.30				LSD (F)	0.13			
LSD (TxF)	0.39				LSD (TxF)	0.29			
2011									
Conventional	3.35	4.91	4.18	4.15^{a}					
Reduced	2.28	4.15	2.83	3.09^{b}					
Minimum	1.21	1.88	1.50	1.53^{c}					
Mean	2.28^{b}	3.65^{a}	2.84^{b}	2.92					
LSD (T)	0.77								
LSD (F)	1.07								
LSD (TxF)	0.54								
Pooled over years					Pooled over years				
Conventional	3.77	5.12	4.44	4.44^{a}	Conventional	4.54	4.45	3.87	4.29^{a}
Reduced	3.12	4.65	3.79	3.85^{b}	Reduced	4.01	4.02	3.93	3.99^{a}
Minimum	2.11	3.80	2.97	2.96^{c}	Minimum	3.18	3.80	3.32	3.43^{b}
Mean	3.00^{c}	4.52^{a}	3.73^{b}	3.75	Mean	3.91^{b}	4.09^{a}	3.71^{c}	3.90
LSD (T)	0.50				LSD (T)	0.41			
LSD (F)	0.50				LSD (F)	0.13			
LSD (TxF)	0.80				LSD (TxF)	0.29			

LSD : Least significant difference at $p < 0.05$ level; Treatments with same letter (a, b, c) are at par with each other; F1 : 100% N (organic); F2 : 50% N (organic) + 50% N (inorganic); F3 : 100% N (inorganic); #: Crop Failed

yield for sustainability and resource use efficiency, regression models were developed by using yields attained by treatments as a function of CRF received in different years as described by Anil Sharma *et al.* (2013) and Maruthi Sankar *et al.* (2013). The slope of a regression model reflected the increasing or decreasing trend in finger millet and pigeonpea yield with an increase in CRF in different years. Based on the relationships of yields attained by treatments with cumulative rainfall received from June to November, the finger millet yield showed a negative correlation with CRF, while pigeonpea yield had a positive correlation with CRF over years. The regression model of finger millet provided yield predictability (R^2) of 0.42 with prediction error of 752 kg ha^{-1}, while the model of pigeonpea provided R^2 of 0.44 and prediction error of 266 kg ha^{-1} over years. The regression models of finger millet yield (Y_{fm}) and pigeonpea yield (Y_{pp}) are:

$$Y_{fm} = 4013^{**} - 7.94^{*}\,(CRF) + 0.007^{*}\,(CRF)^2 \qquad ...(2)$$

$$Y_{pp} = -5102 + 21.343^{*}\,(CRF) - 0.018^{*}\,(CRF)^2 \qquad ...(3)$$

The regression coefficient of CRF indicated that finger millet yield decreased with an increase in the CRF, while pigeonpea yield increased with an increase in the CRF.

Effect of Tillage and Nitrogen Treatments on Soil Parameters

Based on a comparison of the soil parameters observed at the harvest of crops in 2003 and 2011, there was a decrease in the mean soil pH from 5.4 to 4.9, SOC from 0.46 to 0.26%, soil P_2O_5 from 93.9 to 43.9 kg ha^{-1}; while there was an increase in the electrical conductivity from 0.049 to 0.132 dS m^{-1}, soil N from 186.2 to 190.2 kg ha^{-1} and soil K_2O from 136.0 to 168.2 kg ha^{-1} over years. The effect of tillage and N treatments on soil pH, electrical conductivity, organic carbon, N, P_2O_5 and K_2O observed in 2003 and 2011 are given in Table 4. Based on the ANOVA, the tillage and N treatments differed significantly from each other in influencing the soil parameters in both 2003 and 2011. The soil pH ranged from 5.2 to 5.7 with mean of 5.4 in 2003, which decreased to a range of 4.5 to 5.6 with mean of 4.9 in 2011. The electrical conductivity ranged from 0.044 to 0.058 dS m^{-1} with mean of 0.049 dS m^{-1}in 2003, which increased to a range of 0.100 to 0.160 dS m^{-1} with mean of 0.132 dS m^{-1} in 2011.

The SOC ranged from 0.38 to 0.51% with mean of 0.46% in 2003 which decreased to a range of 0.18 to 0.38% with mean of 0.26% in 2011. The soil N was in the range of 154 to 214 kg ha^{-1} with mean of 186.2 kg ha^{-1} in 2003 which increased to a range of 163.7 to 215.8 kg ha^{-1} with mean of 190.2 kg ha^{-1} in 2011. The soil P_2O_5 which was in the range of 53.0 to 145.7 kg ha^{-1} with mean of 93.9 kg ha^{-1} in 2003 decreased to a range of 38.0 to 51.8 kg ha^{-1} with mean of 43.9 kg ha^{-1} in 2011. The soil K_2O which ranged from 108.9 to 188.9 kg ha^{-1} with mean of 136.0 kg ha^{-1} in 2003 increased to a range of 151.7 to 180.9 kg ha^{-1} with mean of 168.2 kg ha^{-1} in 2011.

Based on the LSD criteria, MTF3 was superior in 2003, while RTF2 was superior in 2011 in influencing the soil pH. In case of electrical conductivity, CTF2 was superior in 2003, while CTF1 and RTF1 were at par and superior in 2011. RTF3, MTF1, MTF2 and MTF3 were at par and superior in 2003, while MTF1 was superior in 2011 in influencing the SOC. In case of soil N, MTF2 was superior in 2003, while MTF2 and MTF3 were at par and superior in 2011. CTF2, RTF1 and MTF3 were at par and superior in 2003, compared to MTF3 in 2011 in influencing soil P_2O_5. In case of soil K_2O, RTF2 and MTF3 in 2003, and MTF1 and MTF2 in 2011 were at par and superior compared to other treatment combinations.

Thus MTF3 gave maximum pH and soil K_2O; while CTF2 gave maximum electrical conductivity and soil P_2O_5; MTF1 gave maximum SOC; and MTF2 gave maximum soil N in 2003. Similarly, RTF2 gave maximum pH; while RTF1 gave maximum electrical conductivity; MTF1 gave maximum SOC and K_2O; MTF3 gave maximum soil N and P_2O_5 in 2011. The analysis indicated that minimum tillage tended to maintain a higher soil fertility compared to CT. The treatments which received nutrients either as organics or as a combination of organics and inorganics maintained

Table: 4
Effect of tillage and fertilizer N treatments on soil parameters in 2003 and 2011

Treatment	pH		Electrical conductivity (dS m^{-1})		Soil organic carbon (%)		Soil N (kg ha^{-1})		Soil P_2O_5 (kg ha^{-1})		Soil K_2O (kg ha^{-1})	
	2003	2011	2003	2011	2003	2011	2003	2011	2003	2011	2003	2011
CT F1	5.2^{d}	4.5^{d}	0.044^{c}	0.150^{ab}	0.38^{c}	0.22^{d}	154.0^{e}	163.7^{g}	53.0^{c}	39.0^{d}	108.9^{c}	159.6^{cd}
CT F2	5.4^{bc}	5.0^{b}	0.058^{a}	0.140^{b}	0.46^{b}	0.24^{cd}	185.9^{c}	174.7^{f}	145.7^{a}	38.9^{d}	121.9^{c}	158.2^{de}
CT F3	5.3^{cd}	5.1^{b}	0.044^{c}	0.140^{b}	0.46^{b}	0.18^{e}	187.2^{c}	183.5^{ef}	70.5^{c}	38.0^{d}	114.0^{c}	151.7^{e}
RT F1	5.2^{d}	4.8^{c}	0.045^{c}	0.160^{a}	0.45^{b}	0.32^{b}	182.6^{cd}	185.0^{def}	135.5^{ab}	45.6^{bc}	157.1^{b}	172.4^{b}
RT F2	5.2^{d}	5.6^{a}	0.045^{c}	0.120^{c}	0.43^{b}	0.29^{b}	201.0^{b}	187.3^{de}	61.8^{c}	45.0^{bc}	177.8^{a}	174.3^{b}
RT F3	5.5^{b}	4.6^{cd}	0.051^{b}	0.100^{c}	0.48^{a}	0.22^{d}	174.7^{d}	194.4^{cd}	71.8^{c}	43.4^{c}	127.8^{c}	165.2^{c}
MT F1	5.5^{b}	4.7^{c}	0.053^{b}	0.120^{c}	0.51^{a}	0.38^{a}	187.5^{c}	202.0^{bc}	68.9^{c}	47.2^{b}	113.8^{c}	180.9^{a}
MT F2	5.4^{bc}	4.7^{c}	0.053^{b}	0.120^{c}	0.50^{a}	0.25^{cd}	214.0^{a}	205.5^{ab}	112.4^{b}	46.3^{bc}	113.5^{c}	178.3^{ab}
MT F3	5.7^{a}	4.8^{c}	0.045^{c}	0.140^{b}	0.48^{a}	0.26^{c}	188.7^{c}	215.8^{a}	125.5^{ab}	51.8^{a}	188.9^{a}	173.0^{b}
Mean	5.4	4.9	0.049	0.132	0.46	0.26	186.2	190.2	93.9	43.9	136.0	168.2
CV	3.0	6.7	10.6	14.0	8.5	22.4	8.9	8.5	37.9	10.4	22.5	5.9
LSD	0.1	0.2	0.003	0.012	0.03	0.04	10.8	10.5	23.2	3.0	20.0	6.5

LSD : Least significant difference at $p < 0.05$ level; Treatments with same letter (a, b, c…) are at par with each other; CT : Conventional tillage; RT : Reduced tillage; MT : Minimum tillage; F1 : 100% N (organic); F2 : 50% N (organic) + 50% N (inorganic); F3 : 100% N (inorganic); CV : Coefficient of variation (%)

superior levels of soil fertility compared to treatments with only inorganic nitrogen.

Effect of Tillage and Nitrogen on Profitability of Crops

The cost of cultivation incurred and gross returns, net returns and B:C ratio attained by tillage and N treatments are given in Table 5. Finger millet had a value of ₹10 kg^{-1}, while pigeonpea had a value of ₹ 50 kg^{-1} in the study period. The cost of cultivation ranged from ₹ 10050 to ₹ 12836 ha^{-1} in finger millet and ₹ 13488 to ₹ 19381 ha^{-1} in pigeonpea for MTF3 and CTF1 treatments, respectively. CTF1 gave significantly higher gross returns of ₹ 88964 ha^{-1} and net returns of ₹ 56747 ha^{-1} from finger millet and pigeonpea crops. CTF2 gave maximum net returns of ₹ 31639 ha^{-1} and B:C ratio of 3.65 from finger millet, while CTF1 gave maximum net returns of ₹ 43801 ha^{-1} and B:C ratio of 3.26 from pigeonpea. RTF2 was the 2nd best with net returns of ₹ 25832 ha^{-1} and B:C ratio of 3.31 from finger millet, while RTF1 was the 2nd best with net returns of ₹ 29667 ha^{-1} and B:C ratio of 2.71 from pigeonpea.

Sustainable Yield Index of different treatments

Using the mean finger millet yield attained by tillage treatments, prediction error of 752 kg ha^{-1} and maximum yield of 3752 kg ha^{-1} attained by RTF3 in 2005, SYI values of different treatments were derived and are given in Table 5. Similarly, using the mean pigeonpea yield attained by tillage treatments, prediction error of 266 kg ha^{-1} and maximum yield of 1530 kg ha^{-1} attained by CTF1 in 2010, SYI values of treatments were derived and are given in Table 5. In finger millet, MTF1 had lowest sustainability with SYI value of 14.9%, while CTF2 had maximum sustainability with SYI value of 59.0%. Compared to this, MTF3 had lowest SYI of 9.2%, while CTF1 had highest SYI of 56.6% in pigeonpea. The treatments attained mean SYI of 39.0% with variation of 52.6% in finger millet and 30.1% with variation of 45.1% in pigeonpea over years. This indicated that finger millet had a better sustainability compared to pigeonpea. Based on SYI values, CTF2 was superior for finger millet, while CTF1 was superior for pigeonpea by attaining maximum sustainable yield over years.

The study indicated that CT attained 14.5 and 49.2% higher finger millet yield over RT and MT, respectively. Similarly, F2 was superior over F1 and F3 by attaining 43.8 and 18.3% higher finger millet yield, respectively. Thus the benefit of organic manure and its conjunctive use with inorganics was higher compared to organics or inorganics alone individually for finger millet. However, CTF1 was superior for pigeonpea for attaining maximum yield besides improving the RWUE in different years. CT attained 80.1 and 46.3% higher pigeonpea yield over RT and MT, respectively. Similarly, F1 was superior over F2 and F3 by attaining 24.2 and 55.8% higher pigeonpea yield, respectively. This implied that tilling of soil conventionally and adding 100% N through organic source was beneficial for sustaining yield and profitability of pigeonpea. CTF1 was superior for attaining maximum gross and net returns from finger millet and pigeonpea together with maximum RWUE over years.

When the effects on soil fertility were monitored, use of organics alone or in combination with in organics under minimum tillage were found to be better in maintaining relatively higher soil fertility compared to other treatments. Singh *et al.* (2004) observed the importance of organics in rice-lentil system in Inceptisols and their conjunctive use within organics in sorghum-green gram system (Sharma *et al.,* 2011). Sharma and Mitra (1991) and Das and Mandal (1986) reported that organic manure decomposition induced the transformation and modified the mechanics and dynamics of nutrient mobilization. In this process, the part of nutrients

Table: 5
Effect of tillage and fertilizer N treatments on monetary returns and sustainability yield index in finger millet and pigeonpea

Treatment	Finger millet							Pigeonpea				
	Yield	CC	GR	NR	BC	SYI	Yield	CC	GR	NR	BC	SYI
CTF1	2262^{c}	12836^{f}	25782^{c}	12946^{bc}	1.99^{bcd}	40.2^{c}	113^{2a}	19381^{f}	63182^{a}	43801^{a}	3.26^{a}	56.6^{a}
CTF2	2967^{a}	12043de	43682^{a}	31639^{a}	3.65^{a}	59.0^{a}	929^{b}	18435^{ef}	41229^{bc}	22794^{bc}	2.24^{cd}	43.4^{b}
CTF3	2606^{b}	11500^{cd}	36153^{b}	24653^{a}	3.19^{a}	49.4^{b}	704^{c}	17488de	22787^{def}	5299^{e}	1.3^{f}	28.6^{c}
RTF1	1884de	12111^{e}	17124de	5013^{d}	1.4d^{e}	30.2^{de}	908^{b}	17381de	47048^{b}	29667^{b}	2.71^{b}	42.0^{b}
RTF2	2692^{a}	11318^{c}	37150^{ab}	25832^{a}	3.31^{a}	51.7^{ab}	731^{c}	16435^{cd}	32533^{cd}	16098^{cd}	1.98^{de}	30.4^{c}
RTF3	2264^{c}	10775^{bc}	25573^{c}	14798^{b}	2.41^{b}	40.3^{c}	606^{cd}	15488^{bc}	20618^{ef}	5130^{e}	1.33^{f}	22.2^{cd}
MTF1	1310^{f}	11386^{c}	10682^{e}	-704^{e}	0.94^{e}	14.9^{f}	635^{cd}	15381^{bc}	38102^{bc}	22721^{bc}	2.48^{bc}	24.1^{cd}
MTF2	2185^{cd}	10593^{ab}	22541^{cd}	11948^{bcd}	2.11^{bc}	38.2^{cd}	494de	14435^{ab}	23877^{def}	9442d^{e}	1.65^{ef}	14.9^{de}
MTF3	1758^{e}	10050^{a}	16622de	6572c^{d}	1.65^{c}	26.8^{e}	407^{e}	13488^{a}	17617^{f}	4129^{e}	1.31^{f}	9.2^{e}
Mean	2214	11401	26145	14744	2.29	39.0	727	16435	34110	17676	2.03	30.1
CV	23.1	7.5	41.8	72.6	40.3	34.9	31.4	11.7	43.6	76	34.4	49.6
LSD	340	570	7278	7140	0.62	9.0	152	1278	9912	8952	0.46	10.0

CC: Cost of cultivation (₹ ha^{-1}); GR: Gross returns (₹ ha^{-1}); NR: Net returns (₹ ha^{-1}); Benefit-cost ratio; CV: Coefficient of variation (%); SYI: Sustainable yield index (%); CT: Conventional tillage; RT: Reduced tillage; MT: Minimum tillage; F1: 100% N (organic); F2: 50% N (organic) + 50% N (inorganic); F3: 100% N (inorganic) remained unutilized by one crop in rotation are expected to help growth and development of a succeeding crop in addition to the advantages associated in improving the soil physical properties. Fowler and Rockstrom (2001) found that conservation agriculture would be beneficial for sustainable agriculture, apart from improving the soil fertility in Africa. Conservation agriculture was found to be an efficient option for sustaining the monetary returns and maintaining the soil fertility of nutrients in the Mexican highlands (Govaerts *et al.*, 2009). In our study, the residual effect of organic manure has benefited the succeeding crop. Roul and Mahapatra (2006) found a higher residual fertility effect of conjunctive use of organic and inorganic nutrients in linseed when grown after harvest of rice. This was attributed to slow and sustained release of nutrients, enhanced nutrient use efficiency and improved soil properties (Sarkar and Singh, 1997).

The decreasing trend in finger millet yield indicated about the sufficiency of rainfall for the crop. The increasing trend of pigeonpea yield indicated inadequacy of rainfall and likely response of the crop to an increase in rainfall or more water availability. Though the yield and resource use efficiency parameters like RWUE are important, the fact remains that the prime motive of farmers to do agriculture is to earn higher income and profitability. Efficient management of rainwater would ensure higher productivity and monetary returns from rainfed crops. In a study by Rockstrom *et al.* (2009), the authors described on conservation farming strategies for improving the yield and RWUE under on-farm conditions in east and southern Africa. Our study indicated that finger millet has a better sustainability compared to pigeonpea. CTF2 was superior for finger millet, while CTF1 was superior for pigeonpea by attaining maximum sustainable yield, net returns and B:C ratio under semi-arid Alfisols. In general, practicing summer tillage (conventional method) to kill weed seeds by exposing them to hot weather and capture pre-monsoon and monsoon rainwater in the profile by way of loosening the soil surface and enhancing infiltration rate are two important principles in rainfed agriculture. The CT would also help in loosening the seedbed for good soil aeration, better root growth and ultimately bumper crop growth. The importance of tillage for weed control was highlighted by Richey *et al.* (1977) and Hatfield (1990). They reported that tillage would aid in weed control by killing emerging seedlings, burying seeds, delaying growth of perennials and providing loose surface soil for an efficient action of a herbicide. Due to these benefits, CT was effective in attaining higher monetary returns in the study.

The beneficial effects of reduced tillage could be accrued more effectively, if adequate amount of crop residue is retained on the soil surface on a long-term basis (Lal, 1989; Sharma *et al.,* 2005 and 2008b). Murillo *et al.* (1998) reported on the usefulness of conservation tillage compared to the traditional tillage adopted for rainfed sunflower in southern Spain. In a similar study by Oicha *et al.* (2010), the authors found usefulness of conservation tillage for sustaining the yield of Tef under Vertisols in northern Ethiopian highlands. While highlighting the importance of tillage in dryland crops of sorghum and pearl millet, Vittal *et al.* (1983) reported that deep tillage up to 23 cm helped in improving the grain yield by better moisture recharge of soil profile and enhancing the rooting depth in Alfisols. The rainfed soils are low in organic carbon and soil N. The response and performance of either organics alone and in conjunction with inorganic fertilizers would remain superior because of improved soil condition and sustained release and availability of nutrients resulting in higher use efficiency (Nambiar, 2002; Sharma *et al.,* 2008a). In the long-term, tilling a soil more and more or using inversion tillage with implements like mould-board plough would be harmful to the soil quality, but in the short-term, the yield gains would remain higher with CT than under low tillage (Sharma *et al.,* 2008b; Venkateswarlu *et al.,* 2010).

Our study has shown that CT is essential for both finger millet and pigeonpea, and would provide significantly higher monetary returns in combination with 50% N through organic source + 50% N through inorganic source for finger millet and 100% N through organic source for pigeonpea under semi-arid Alfisols. Application of N either as organics or as a combination of organics and inorganics maintained superiority for soil fertility compared to only inorganic N. In the mostly sub-tropical and tropical environment existing in the Indian sub-continent, where lands are mostly at the verge of degradation with deteriorated soil quality, the studies that warranted a shift of CT to the reduced or minimum tillage are highly relevant for future. However, such studies should be conducted on long-term basis using appropriate reduced tillage levels. The results of our study are not only useful to the given location under semi-arid Alfisols, but could also work as an analogy for developing a similar relationship for other crops in different rainfed tropics across the world.

4. CONCLUSIONS

Based on the study conducted in semi-arid Alfisols with finger millet-pigeonpea under rotation at Bangalore during 2003 to 2011, efficient tillage and nitrogen practices have been identified for attaining maximum sustainable yield and monetary returns. On the basis of SYI, net returns and B:C ratio, CTF2 was superior for finger millet, while CTF1 was superior for pigeonpea. CTF2 gave maximum SYI of 59.0% with net returns of ₹ 31639 ha^{-1} and B:C ratio of 3.65 from finger millet, while CTF1 gave maximum SYI of 56.6% with net returns of ₹ 43801 ha^{-1} and B:C ratio of 3.26 from pigeonpea. This indicated that CT is essential for both crops, while 100% N through organic source would be profitable for pigeonpea and 50% N through organic source+50% N through inorganic source would be profitable for finger millet. Based on the soil parameters observed in 2003 and 2011, the pH, soil P and organic carbon had decreased, while electrical conductivity, soil N and K had increased. Application of N through organics or as a combination of organics and inorganics maintained a higher soil fertility compared to only inorganic N. In the mostly sub-tropical and tropical soils of India which are degraded and have a deteriorated soil quality, the studies that warrant a shift of conventional tillage to reduced or minimum tillage are highly relevant for future. The findings of our study are applicable to finger millet and pigeonpea grown under similar soil and agro-climatic conditions in any region.

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