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Nitrogen Use Efficiency of Sorghum + Cowpea, Cotton + Blackgram Rotation Based Inter-Cropping System Under Varied Source of Fertilizer Application in Long Term Manurial Experiment in Dryland Vertisols

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Long term manurial field experiments were conducted with thirteen treatments replicated thrice comprising of full and 50 % recommended dose of N as inorganic and organic source as individual and in combination with and without P (half and full dose) as inorganic in a randomized block design using sorghum (*Sorghum bicolor* L. Moench) + cowpea (*Vigna unguiculata*) intercropping system rotated with a cotton (*Gossypium hirsutum*) + blackgram (*Vigna mungo*) intercropping system in a semi-arid Vertisol during 1995 to 2008 to evaluate N use efficiency of nutrient management techniques. Generally, the crops were sown in the month of October-November and harvested in the month of January-February during the *Rabi* **season in all the years. Improved crop varieties alone will not be sufficient to increase production unless adopting the suitable agronomic and efficient nutrient management practices. Nitrogen ranks first among the applied inputs to maximize output in agriculture. Nitrogen use efficiency can be described as the output of economic produce by any crop per unit of nitrogen applied under specific set of soil and climatic conditions. In general, the sorghum + cowpea intercropping system was more efficient in utilizing the applied N than the cotton+blackgram intercropping system under long term manurial experiment in dryland vertisols. The average partial factor productivity was 65.93 and 22.63 kg grain kg (N)$_{-1}$ in sorghum+cowpea and cotton+blackgram intercropping system respectively. The more partial factor productivity in sorghum+cowpea inter-croppings system was due to variation in N uptake between the intercropping systems. The agronomic efficiency was maximum under the incorporation of N in equal combination of organic and inorganic (25.70 and 7.11 kg grain kg (N)$_{-1}$) in both sorghum+cowpea and cotton+blackgram intercropping systems followed by the application of N as organic. The more physiological efficiency indicated the conversion of absorbed N into economic product more efficiently under the conjuctive use of N as both organic and inorganic in sorghum+cowpea and by the application of organic alone under the cotton+blackgram intercropping system. The higher recovery efficiency under conjunctive use of organic and inorganic in both intercropping system was due to the less leaching loss of N and higher uptake of N. The net negative nitrogen balance registered in the millet intercropping system was due to the poor utilization of nitrogen absorbed by the sorghum+cowpea intercropping system as evidenced from the registered higher mean agronomic efficiency**

Key words: Nitrogen, N use efficiency, Nitrogen balance, Intercropping system, Vertisols, Drylands

The world's oldest long term agricultural field experiments were begun between 1843 and 1856 by Lawes and Gilbert at Rothamsted in England. Eight of these experiments still continue. In the beginning of 20^{th} century, based on Rothamsted model, a series of long term fertilizer experiments were established at different locations in India. These were at Kanpur, Uttar Pradesh (1905); Pusa, Bihar (1908); and at Coimbatore, Tamil Nadu (1909). Unfortunately, some of these experiments were either discontinued or seriously altered as they were found inadequate in respect of the statistical requirement pertaining to the design of experiments or suffered from some management problems. However, the trials at Coimbatore and Ranchi are still being continued. Based on the results obtained at Coimbatore centre, the Tamil Nadu Agricultural University started eleven Permanent Manurial Experiments at various locations in the province / state. These experiments represent different soil conditions and cropping systems. One of such experiments was conducted at Agricultural Research Station, Kovilpatti to find out the cumulative effect of both organic and inorganic fertilizers' response on the predominant intercropping system of sorghum+cowpea and cotton+blackgram rotation based intercropping system and to assess the soil nutrients build up in this long term manurial experiment from 1995 onwards.

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Vertisols are a predominant soil group found across the world. The majority of the acreage of Vertisols and associated soils in the world is distributed in Australia (70.5 million ha), India (70 million ha), Sudan (40 million ha), Chad (16.5 million ha), and Ethiopia (10 million ha). These five countries constitute more than 80 % of the total area (250 million ha) of Vertisols in the world (Dudal 1965). In India, substantial Vertisol areas are found in the province of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, and Tamil Nadu (Maruthi Shankar,et al., 2012). Most of these regions receive 500 to 1300 mm of annual rainfall, concentrated in a short period of 3 to 3.5 rainy months interspersed with droughts. A key factor in maintaining long-term production in Vertisols of Kovilpatti regions of southern India are adequate moisture availability, balanced application of nutrients, and improvement of organic matter in soil with the predominant intercropping systems in these regions include sorghum + cowpea and cotton + blackgram (Maruthi Shankar, et al., 2012).

The millets especially sorghum and cotton based intercropping systems are the major systems in the Vertisols (Musa *et al*., 2012) of Southern Tamil Nadu under rainfed condition. Improved varieties alone will not be sufficient to increase production unless adopting the suitable agronomic and efficient nutrient management practices. Both sorghum and cotton require higher amount of nutrients especially N, but their prohibitive cost frequently defers farmers from its use in right quantities and in balanced proportions especially in drylands. The effects of various fertilizer management practices though the use of organic and inorganic sources of N in varied proportions with and without P on a fixed rotation of sorghum and cotton based intercropping systems in vertisols under dry farming regions of Southern Tamil Nadu and its response to NUE were studied for the last 14 years and presented in this paper.

Materials and Methods

Field experiments were conducted on sorghum (*Sorghum bicolor* L. Moench) + cowpea (*Vigna unguiculata*) intercropping system rotated with a cotton (*Gossypium hirsutum*) + blackgram (*Vigna mungo*) intercropping system in a permanent manurial site in a semi-arid Vertisol at Kovilpatti center during 1995 to 2008 situated in the typical Vertisol belt in the southern zone of Tamil Nadu uplands and leeward flanks of South Sahayadri and Deccan (Karnataka) Plateau and lies between 8^{o} 43' and 9^{o} 20' North latitude and 77^{0} 4' and 78^{o} 26' East longitude at 90 m above MSL. The climate is hot and semi-arid with a mean annual rainfall of 743 mm and potential evapotranspiration of 812 mm. The experiment was laid out in a randomized block design with 13 conjunctive nutrient management treatments in three replications with sorghum + cowpea intercropping system during 1995-96, 1997-98, 1999-2000, 2001-02, 2003-04, 2005-06, and 2007-08 and rotated with cotton + blackgram intercropping system during 1996-97, 1998-99, 2000-01, 2002-03, 2004-05, 2006-07 and 2008-09. Totally there were 14 systems were raised with cotton + blackgram and sorghum + cowpea for 7 years each. The cotton varieties raised in this experiment were KC2 for 6 years and MCU10 for 1 year. The blackgram varieties grown were K1, CO5 and VBN3 for each 2 years and CO4 for 1 year. With respect to sorghum-cowpea intercropping system, the sorghum with the variety of K8 and the cowpea with the variety of C152 were raised during all the 7 years period.

The conjunctive nutrient management treatments involve application of 50 % and 100 % recommended dose of N as organic (FYM) and inorganic (Urea) N, as alone and in combinations, with and without P and which were described as (i) control; (ii) 20 kg N ha^{-1} (urea); (iii) 40 kg N ha^{-1} (urea); (iv) 20 kg N ha^{-1} (urea) + single superphosphate (SSP) at 10 kg P ha^{-1}; (v) 40 kg N (urea) + 20 kg P ha^{-1} (SSP); (vi) 20 kg N ha^{-1} farmyard manure (FYM); (vii) 40 kg N ha^{-1} (FYM); (viii) 20 kg N (FYM) + 10 kg P ha^{-1} (SSP); (ix) 40 kg N (FYM) + 20 kg P ha^{-1} (SSP); (x) 10 kg N (urea) + 10 kg N ha^{-1} (FYM); (xi) 20 kg N (urea) + 20 kg N ha^{-1} (FYM); (xii) 10 kg N (urea) + 10 kg N ha^{-1} (FYM) + 10 kg P ha^{-1} (SSP); and (xiii) 20 kg N (urea) + 20 kg N (FYM) + 20 kg P ha^{-1} (SSP). Nitrogen was applied through FYM (N content 0.5%) and inorganic N (urea), while P was applied through SSP. Treatments were randomized during the first year, and subsequently the same treatments were applied to the same plots at every year. The soil of the experimental site is *Typic Chromustert* with clayey texture , pH: 8.2, EC: 0.5 dS m^{-1} , organic C: 4.3 g kg^{-1}, available N: 80 kg ha^{-1}, available P: 10 kg ha^{-1} and available K: 586 kg ha^{-1}. Soil samples drawn after the harvest of the every test crop were dried, processed and analyzed.

Generally the crops were sown in the month of October-November and harvested in the month of January-February during the Rabi season in all the years. Five plants were collected randomly in each plot at physiological maturity. The economic product and stalk were separated. The separated plant samples were kept in brown covers and sun dried first and later oven dried at 70-80°C for 72 hours. After recording the dry weight, each sample was ground in a Wiley mill and sub samples were obtained for laboratory analysis. The N content in the plant was estimated by Kjeldahl digestion method (Yoshida and Cornel, 1976) using di-acid mixture and uptake was computed.

The data of both main and intercrop grain yield, amount of N applied through organic and inorganic sources and nitrogen uptake by the crop (main + intercrop) were used for deriving various N use efficiencies of the intercropping systems followed. The nutrient use efficiency is calculated in different terms depending upon the perspective in which it is computed and considered. The efficiency with which the native and applied N through organic and inorganic alone and in combination used by the crop towards grain production was evaluated through partial factor productivity, agronomic efficiency, physiological efficiency and recovery efficiency. Partial factor productivity **(**P_{fp}) represents the combined effect of native as well as the applied N. It is the ratio of grain yield to the applied N and computed as Y/Nt. The term which represents the efficiency of applied nitrogen in terms of incremental efficiency from an applied N is often called as the agronomic efficiency (ε_a) and computed as ΔY/Nt. The physiological efficiency (ε_p) is the efficiency with which the crop utilizes the acquired N to produce more grains and calculated as ΔY/ΔNu. The recovery efficiency (ε_R) is the percentage of N uptake from the applied N and derived as (ΔNu/Nt)x100. The nitrogen balance in terms of net gain or net loss of nitrogen was computed from the nitrogen status ($KMnO_4$-N) of the soil before and after harvest, quantity of nitrogen applied as organic and inorganic sources and the uptake of nitrogen by the intercropping systems. The calculated quantity of nitrogen balance was compared with theoretical (measured) balance of nitrogen present in soil.

Results and Discussion

Nitrogen use efficiency

Nutrient use efficiency can be described as the output of economic produce by any crop per unit of nutrient applied under specific set of soil and climatic conditions (Mikkelsen and De Datta, 1991). Nutrient use efficiency is conceived as the product of uptake efficiency, ie the ratio of actual uptake to potential supply, and utilization efficiency, i.e., the ratio of yield to actual uptake. Both depend on the availability of the nutrient in relation to other growth factors, and require N, P and K perfectly in balance to reach their maximum values (Janssen, 1998). In this paper, the N use efficiency has been assessed though partial factor productivity, agronomic efficiency, physiological efficiency and recovery efficiency and presented below.

In general, the sorghum + cowpea intercropping system was more efficient in utilizing the applied N due to higher grain yield than the cotton+blackgram intercropping system under long term manurial experiment in dryland vertisols. There were no variations between the types of efficiencies under sorghum+cowpea intercropping system, whereas the agronomic efficiency was distinctly varied from the other efficiencies under cotton+blackgram intercropping system (Fig1 and 2) due to poor utilization of applied N.

Partial factor productivity (PFP)

Partial factor productivity (PFP) for applied N is a useful measure of NUE because it provides an integrative index that quantify total economic output relative to utilization of N in the system, including the indigenous soil N supply and applied N (Cassman *et al*., 1993). Partial factor productivity reflects both

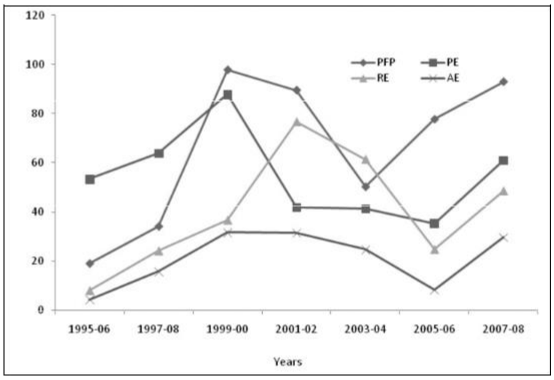


Fig. 1. Nitrogen use efficiency (kg kg (N)-1) of sorghum+ cowpea intercropping system under LTM in vertisols

agronomic efficiency (AE) and the balance between the indigenous soil N supply and applied N. The partial factor productivity ranged from 39.29 to 88.92 kg grain kg (N)$^{-1}$ and recorded as the highest efficiency

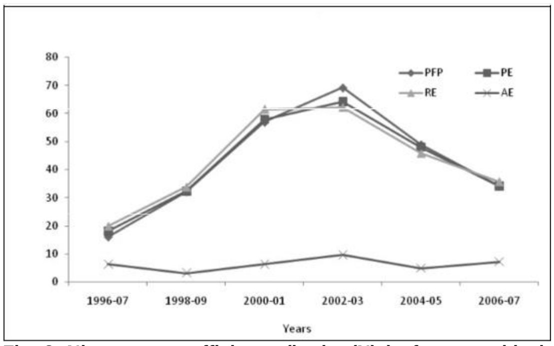


Fig. 2. Nitrogen use efficiency (kg kg (N)-1) of cotton+ black gram intercropping system under LTM in vertisols

among the various types of N use efficiencies under sorghum+cowpea intercropping system (Table 1 and 2). The same was from 13.90 to 33.15 kg grain kg (N)$^{-1}$ and registered highest efficiency next to physiological efficiency under cotton+blackgram

Table 1. Nitrogen use efficiency of sorghum+ cowpea intercropping system under varied source of N in long term manurial experiment in dryland vertisols

Source and levels of N	Nitrogen Use Efficiency (kg grain kg (N)$^{-1}$)			
	PFP	AE	PE	RE
FN (20)	79.59	19.34	54.96	41.12
FN (40)	39.29	9.16	44.60	20.37
FN(20) + P (10)	84.27	24.02	59.56	51.60
FN (40) + P (20)	46.03	15.91	54.30	31.41
Mean (Inorganic alone)	62.30	17.11	53.35	36.12
ON (20)	78.70	18.45	52.22	37.21
ON (40)	45.08	14.96	54.32	26.00
ON(20)+ P (10)	84.55	24.30	56.74	48.78
ON(40) + P (20)	50.09	19.96	54.06	36.37
Mean (Organic alone)	64.61	19.42	54.33	37.09
FN(10) + ON (10)	88.64	28.39	53.24	54.34
FN(20) + ON (20)	50.42	20.29	50.89	37.69
FN(10) + ON(10) + P (10)	88.92	28.67	57.47	49.58
FN(20) + ON(20) + P (20)	55.55	25.43	65.48	46.62
Mean (Integrated)	70.88	25.70	56.77	47.06

intercropping system. The average partial factor productivity was 65.93 and 22.63 kg grain kg $(N)^{-1}$ in sorghum+cowpea and cotton+blackgram intercropping system respectively. The more partial factor productivity in sorghum+cowpea intercroppings system than cotton+blackgram was due to variation in N uptake between the intercropping systems as observed by Jothimani (2012). Application of organic and inorganic sources of N in equal combination recorded highest partial factor productivity than the application of either inorganic or organic source of N alone which registered lowest partial factor productivity in both the intercropping system under long term manurial experiment in Vertisol irrespective of the level of N applied. The high PFP under the combined application of organic and inorganic sources of N could be attributed to higher N uptake both from native (soil) and applied N leading to higher yield as reported by Juliardo and Abdulrachman (1997). Among the levels, application of 50 % of recommended dose of N (10 kg N ha^{-1}) either as organic or inorganic or in combination produced higher partial factor productivity in both the cropping system than 100 % recommended dose of N due to effective utilization of applied nitrogen for grain production (Jothimani, 2012). However, the incorporation of phosphorus along with nitrogen registered higher partial factor productivity (Fig.1 and 2) than the application of nitrogen alone in both the intercropping system.

Agronomic efficiency (AE)

The AE represents the product of physiological efficiency (PE) with which the crop utilizes the acquired N to produce more grain and the recovery efficiency (RE) of applied nitrogen (Stalin *et al*., 1999). Among the two intercropping systems followed under long term manurial experiment in vertisols, the sorghum + cowpea had higher agronomic efficiency than cotton + blackgram due to higher nutrient absorbing capacity as observed from negative N balance under this intercropping system (Fig.4). It varied from 9.16 to 28.67 and 3.45 to 9.55 kg grain kg $(N)^{-1}$ in sorghum+cowpea and cotton+blackgram intercropping systems respectively (Tables 1 and 2). The agronomic efficiency was maximum under the incorporation of N in equal combination of organic and inorganic (25.70 and 7.11 kg grain kg $(N)^{-1}$) followed by the application of N as organic which registered the agronomic efficiency of 19.42 and 6.26 kg grain kg $(N)_{-1}$ than inorganic N alone in sorghum+cowpea and cotton+blackgram intercropping systems respectively. Since the plant growth and N uptake are closely interrelated with each other, it is difficult to determine whether poor AE is due to the inability of the plant to recover N or the inability of the plant to utilize that N for growth and yield production (Craswell and Godwin, 1984). In most cases, inefficient plant recovery of applied N is the largest constraint to agronomic efficiency. With respect to levels, application of 50 % recommended dose of N either organic or inorganic registered the highest agronomic efficiency than 100 % recommended dose of N in all combinations due to effective utilization of applied N.

Physiological efficiency (PE)

In general, both sorghum+cowpea and cotton+blackgram intercropping system had almost equal physiological efficiency than other efficiencies under long term manurial experiment in vertisol.
The physiological efficiency ranged between 44.60 (N as inorganic alone) and 65.48 (integrated use of organic and inorganic N) in sorghum+cowpea intercropping system and from 43.80 (N as inorganic alone) to 62.84 kg kg $(N)_{-1}$ (organic N alone) in cotton+blackgram intercropping system (Tables 1 and 2). Both the intercropping systems were influenced by the same and equal environmental stresses (since they cultivated in same season in same soil) which were important determinants of portioning of crop dry matter production between grain, straw and roots and affect physiological efficiency (Alessi *et al*., 1979). As that of the other efficiencies, the physiological efficiency was also higher under application of N as both organic and inorganic source in an integrated manner in sorghum+cowpea intercropping system whereas the maximum physiological efficiency was recorded by the application of organic form of N in cotton+blackgram intercropping system irrespective of the level of N added. This indicate that the conversion of absorbed N into economic product was more efficient under the conjuctive use of N as both organic and inorganic in sorghum+cowpea. Jain and Sharma (2009) also observed higher uptake and efficiency of all the three major nutrients with the application of chemical fertilizers in conjunction with FYM as compared to application of chemical fertilizers alone. The registered higher agronomic efficiency under application of organic N alone in cotton+blackgram intercropping systems paves the idea for the production of organic cotton.

Recovery efficiency (RE)

The fraction of applied N that is absorbed by a crop is expressed as apparent N recovery and is calculated as the ratio of actual uptake minus uptake in unfertilized plots, to the applied amount of N. Lower recovery of applied N is one of the important constraints to crop yield and production especially in the Asian tropics (De Datta, 1981; Patrick, 1982). The mean recovery efficiency ranged from 20.37 to 54.34 and 5.81 to 21.61 % in sorghum+cowpea and cotton+blackgram intercropping systems (Table 1 and 2). With respect to sources of N applied, the combined application of organic and inorganic N in equal proportion registered higher mean recovery efficiency in both the cropping systems. The higher recovery efficiency under conjunctive use of organic and inorganic in both intercropping systems was due to the less leaching loss of N and higher uptake of N (Nye and Tinker, 1977). However, incorporation of 50 % recommended dose of N as both organic and inorganic and as organic source alone registered higher recovery efficiency in sorghum+cowpea and

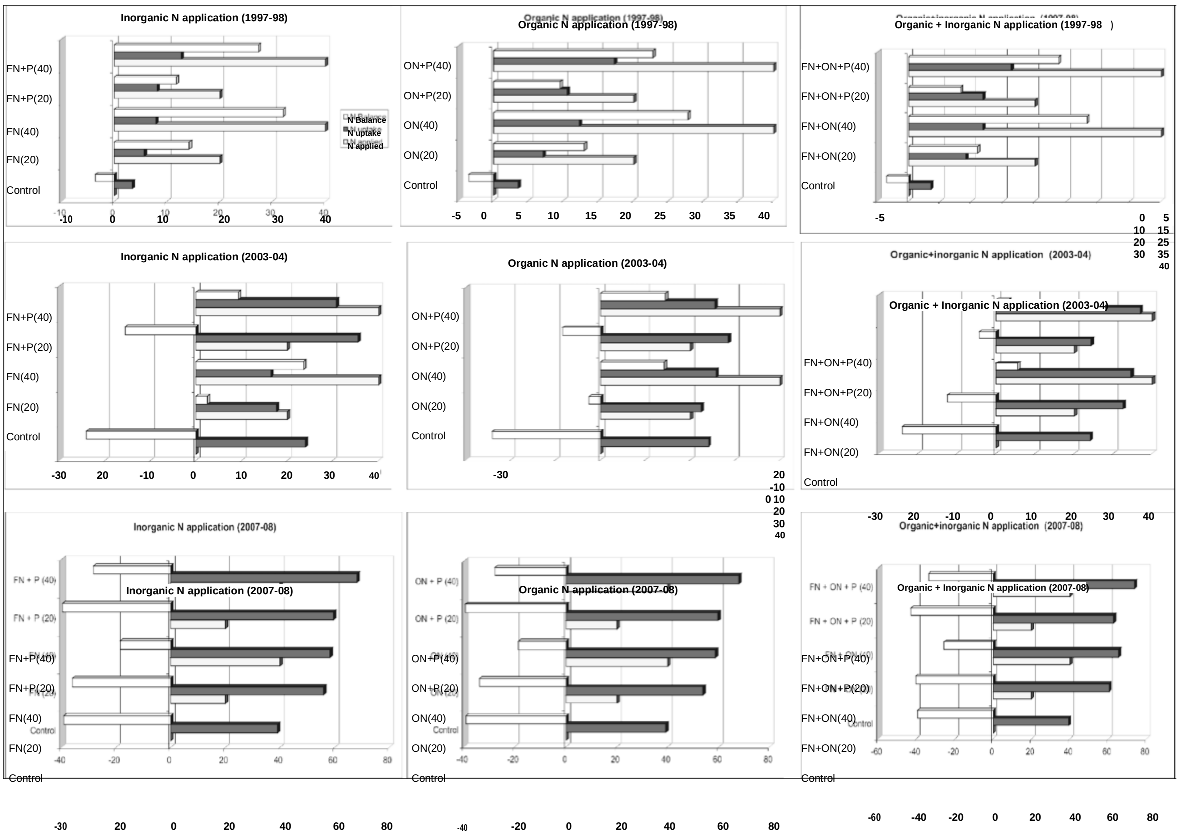
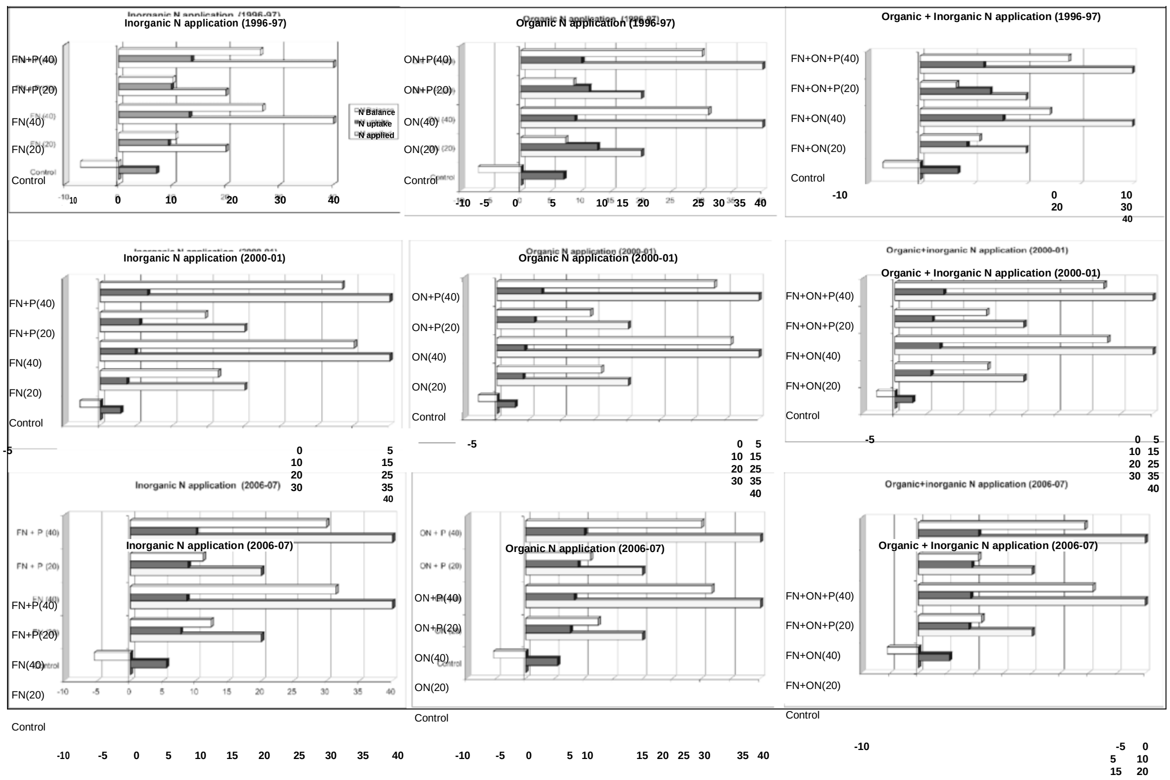


Fig 3. Nitrogen balance under sorghum+cowpea intercropping system under long term manurial application in dryland Vertisols

cotton+blackgram intercropping systems respectively. Yadav and Yadav (1997) indicated that the recovery of N decreased with increasing levels of N application due to reduced surface of fertilizer particles to contact with soil.

Nitrogen balance

Nitrogen balance in terms of net gain or net loss of nitrogen was computed from the nitrogen status of the soil before and after harvest, quantity of nitrogen applied as organic and inorganic sources and the



25 30 35 40

Fig 4. Nitrogen balance under cotton+blackgram intercropping system under long term manurial experiment in dryland Vertisols

uptake of nitrogen by the crop. The calculated quantity of nitrogen balance was compared with theoretical (measured) balance of nitrogen present in soil. In general, the net nitrogen balance was always positive for all the nutrient management techniques (treatments) followed throughout the period of cultivation of cotton+blackgram intercropping system and it was positive during the initial period and negative in soil receiving 50 % of recommended dose of N either as organic or inorganic or in combination during the middle period of cultivation and more negative in all the nutrient management techniques (treatments) during later cultivation period of sorghum+cowpea intercropping system (Fig. 3 and 4). The net negative nitrogen balance registered in the millet intercropping system was due to the poor utilization of nitrogen absorbed by the sorghum+cowpea intercropping system as evidenced from the registered higher mean agronomic efficiency (Table 2). Among the various nitrogen sources, application of nitrogen through organic in combination with reduced recommended dose of nitrogen (50 %) showed higher intensity of net negative nitrogen balance due to the immobilization of biological processes of nitrogen transformation (Duhan *et al*., 2005).

Table 2. Nitrogen use efficiency of cotton+ blackgram intercropping system under varied source of N in long term manurial experiment in dryland vertisols

Source and levels of N	Nitrogen Use Efficiency (kg grain kg (N)$^{-1}$)			
	PFP	AE	PE	RE
FN (20)	24.07	5.56	69.19	8.48
FN (40)	14.74	3.49	43.80	7.96
FN(20) + P (10)	28.00	6.98	53.72	15.13
FN (40) + P (20)	15.93	5.80	46.38	13.16
Mean (Inorganic alone)	20.69	5.46	53.27	11.18
ON (20)	33.53	6.72	62.84	11.08
ON (40)	13.90	3.45	59.48	5.81
ON(20)+ P (10)	27.71	9.26	47.36	21.61
ON(40) + P (20)	15.67	5.61	47.71	12.83
Mean (Organic alone)	22.70	6.26	54.35	12.83
FN(10) + ON (10)	33.15	6.56	44.06	14.57
FN(20) + ON (20)	15.84	5.87	44.38	13.44
FN(10) + ON(10) + P (10)	32.78	9.55	52.56	19.55
FN(20) + ON(20) + P (20)	16.22	6.48	46.86	14.01
Mean (Integrated)	24.50	7.11	46.96	15.39

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