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Nutrient balances—a guide to improving sorghum- and groundnut-based dryland cropping systems in semi-arid tropical India

T.J. Rego*, V. Nageswara Rao, B. Seeling, G. Pardhasaradhi, J.V.D.K. Kumar Rao

Natural Resource Management Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru 502 324, Andhra Pradesh, India

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Abstract

Information on soil–plant nutrient balance in India and elsewhere is scarce and mostly generalized. A review of earlier studies on nutrient balances was done to assess their relevance for researchers, policy makers, and farmers' understanding, to manage soil fertility for sustainable crop productivity. An on-farm nutrient balance study during 1995/1996 and 1996/1997 was designed to understand nutrient balances resulting from farmers' practices in semi-arid tropical regions of India. This diagnostic study targeted sorghum-based cropping systems and groundnut-based cropping systems in low rainfall areas of the Indian SAT. Selection of farmers for this study was done through a systematic survey and analyses of factors effecting farmers' decision making for nutrient inputs. Intensive plot-specific nutrient input and output measurements were carried out on 53 farmers' fields for sorghum-based systems and 45 farmers' fields for groundnut-based system in this study. Topsoil mineral nitrogen (N) content observed in 2 years at the beginning of the crop season in two locations of Andhra Pradesh, India, was surprisingly high and exchangeable potassium (K) contents also indicated sufficient supply in most fields. Available phosphorus (P) in the majority of fields in both locations was around threshold levels, and just sufficient for most crops. The nutrient balance in sorghum-based systems indicates a moderate to higher negative balance of potassium leading to soil mining for potassium supply in these systems. Nitrogen and P balances were generally positive. Although the groundnut-based system accumulated 53% of its N requirements through BNF, negative balances of N and K were observed mainly due to low applications of these nutrients. Application of K along with options for improving BNF of groundnut are suggested. Better nodulating groundnut cultivars and efficient rhizobium strains need to be introduced. High positive balances were observed in the systems whenever commercial crops like castor and cotton were sown in the rotation. This indicates farmers' preferences for applying excess quantities of FYM to commercially important crops even in dryland farming systems. The replenishment costs of mined nutrients annually in different cropping systems were calculated based on current market prices of inorganic fertilizers.

Keywords: Alfisols; Cropping systems; Farmers' fields; Nutrient mining; Nutrient balances; Organic inputs; Crop uptake

1. Introduction

Nutrient balance studies in sub-Saharan Africa have shown that the depletion of soil nutrients is one of the most important problems facing sustainable agriculture in this region. The average nutrient loss was determined as 22 kg N, 2.5 kg P, and 15 kg K ha^{-1} per year in 1982–1984 and predicted to reach 26 kg N, 3 kg P, and 19 kg K ha^{-1} per year in the year 2000 (Stoorvogel et al., 1993). However, countrywide balances like these have scale limitations.

* Corresponding author.

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Information on nutrient depletion in India is surprisingly scarce. N nutrient depletion in dryland agricultural systems is generally expected since the inputs of purchased fertilizers and FYM is traditionally low (Jha and Sarin, 1984). Nutrient balances can be calculated on various scales, e.g. national or regional level, farms of a particular farming system or fields of a particular cropping system. A district level study in Kenya determined substantial depletion of 112 kg N, 3 kg P, and 70 kg K ha^{-1} per year (Smaling et al., 1993). Much of the published data in India is on the national and regional level and deals only with mineral fertilizer inputs and estimates of crop nutrient uptake.

1.1. National scale fertilizer input—crop uptake estimates and balances

The gap between fertilizer inputs and nutrient removal in India has remained nearly the same during the past 20 years, despite a steady increase in fertilizer consumption (Tandon and Narayan, 1990). In the years 1988/1989, crop nutrient ($N + P_2O_5 + K_2O$) uptake was 20.7×10^6 t whereas fertilizer inputs amounted to 11.0×10^6 t leaving a gap of 9.7×10^6 t or 55 kg ha^{-1} (Biswas and Tewatia, 1991). There are considerable differences between the nutrient balances in different agro-ecological regions. The presentation of data as aggregated total nutrient (NPK) consumption and removal makes it impossible to identify depletion of a specific nutrient. It also prevents any estimate of nutrient loss mechanisms other than nutrient removal with harvested products.

1.2. Agro-ecoregional (AER) scale fertilizer input—crop uptake balances for irrigated and rainfed systems

Fertilizer input is less favored for rainfed systems than for the region as a whole. For example, although 84% of the cropped area in the Indian state of Karnataka is rainfed, only 22% of this land receives fertilizers, which amounts to only 23% of the total applied fertilizer N (Table 1). The situation for P and K fertilizers is about the same. Although dryland systems seem to be more likely to have negative nutrient balances, most of the work on nutrient balances of specific cropping systems in India has been done on irrigated systems, most likely because these systems are more important economically for national food security.

The nutrient balances of intensive cropping systems are a good example of nutrient mining caused by imbalanced application of nutrients. Application of only N and P increases biomass production if other nutrients are not limiting. For potassium, the applied amounts are often considerably less than the large quantities removed in crop residues and fodder; consequently, the budget deficit is large. In rainfed cropping systems with less fertilizer inputs, yield level and nutrient mining depends more on the inherent soil fertility than on applied nutrients. In addition, FYM is applied preferentially to irrigated land and cash crops (Jha and Sarin, 1984).

1.3. Farm/plot scale fertilizer input—crop uptake balances for cropping systems on research stations

Based on fertilizer input and crop uptake, Nambiar and Ghosh (1987) calculated the K balance of irrigated crop rotations in long-term experiments from several locations in India. Even the application of the recommended K fertilizer was not sufficient to balance crop removal. Thakur et al. (1990) reported NPK balances in trials in northern India with maize–wheat, rice–wheat, soybean–wheat and groundnut–wheat rotations fertilized with recommended rates. The N and P

Table 1
NPK application in rainfed agriculture of three states in the Southern Plateau and Hills region of India (Tandon, 1981)

State	Cropped area rainfed (%)	Rainfed area fertilized (%)	Total fertilizer nutrients applied to rainfed crops (%)		
			N	P	K
Karnataka	84	22	23	26	24
Andhra Pradesh	54	13	10	12	14
Tamil Nadu	43	9	3	4	4

balances were positive in all rotations with the exception of a slightly negative balance in the soybean–wheat rotation (-4 kg N ha^{-1} per year). However, inconsistent response to K application in long-term fertilizer trials shows that most soils buffer crop demand for K, even in intensive cropping systems, for several years. This is further supported by the fact that the difference of extractable soil K between fertilized and non-fertilized treatments remained constant over a period of 11 years (Nambiar and Ghosh, 1987). Another deficiency of these nutrient balance studies is that most of the work in India was done on research stations with recommended fertilizer rates which is of limited relevance to real world situations in farmers' fields. Particularly, very little information is available on nutrient balances in less endowed dryland cropping systems.

Scoones and Toulmin (1998) analyzed a number of scale-inherent pitfalls and suggested that applying nutrient balances at the scale where they are expected to have impact is of paramount importance. Since individual farmers take decisions on nutrient management based on the crops and cropping systems, we targeted our comprehensive study on nutrient management to farmers' fields with twin objectives: (i) to diagnose the nutrient imbalances affecting the productivity of the most prominent cropping systems of the regions under study; (ii) to guide farmers on optimal interventions to sustain soil quality through nutrient balances, even with intensive cropping in the drier parts of the Indian SAT.

2. Material and methods

2.1. Selection of cropping systems

A time-series analysis of crop statistics of dryland cropping systems on Alfisols had shown that two cropping systems were of primary importance, under semi-arid conditions in two regions of the state of Andhra Pradesh, India. The sorghum-based (40% of net cultivated area) cropping systems in the Mahboobnagar district of southern Telangana region are the main food and fodder systems that support the livelihoods of 2.73 million rural inhabitants, and provide fodder for 9.22 million cattle mainly through sorghum fodder. The other is the groundnut-based system in the Anantapur district of Rayalaseeema region, which occupies 77% of the net cultivable area, supporting ≈2.43 million rural inhabitants on subsistence incomes, and meeting the fodder requirements of 6.63 million cattle. In order to obtain reliable data on nutrient management in these dryland cropping systems, we conducted a nutrient balance study that was limited to the major nutrients nitrogen, phosphorus, and potassium on farmers' fields in the two systems.

Traditionally, a sorghum–castor rotation is practiced in successive rainy seasons on Alfisols in parts of semi-arid tropical India. Alfisols in these regions are typically shallow or very shallow (0.30–1.00 m) with low water holding capacity ranging from 50 to 180 mm. The cropping systems prevalent in these regions are about 110–135 days in duration, as the rainy season commences by the second week of June and recedes by the end of September. The annual rainfall varies between 540 and 705 mm.

The term rotation is applied loosely in this context, as farmers *intend* to rotate sorghum with castor. The frequency of this rotation depends on the soil quality; the location of the land; as well as seed availability and prevailing market prices of the crop product. Pigeonpea is generally intercropped either with sorghum or castor in this system. In addition to being a subsistence food grain, sorghum is the most important source of fodder for draft and milk cattle in this farming system, which still relies largely on draft animals for farm operations.

The center of the groundnut growing area is the Anantapur district in the southern tip of the state of Andhra Pradesh. The groundnut-based cropping system is also followed in adjoining districts where rainfall patterns are similar. Intermittent dry periods commonly occur after the emergence of the crop. In addition, most parts of the area are covered by extremely shallow soils of low water holding capacity, aggravating the water problem. Groundnut seems to be the only dryland crop which withstands this unfavorable rainfall pattern. For this reason, and because groundnut is a valuable oil seed cash crop, the area is basically a groundnut monoculture.

2.2. Initial survey and selection of villages and farmers

After identifying the prominent cropping system for each study region, an initial survey was carried out to

Table 2
Questions in the initial survey

Family size and structure, non-farm income, hired labor
Farm size
Livestock
Soil types (area)
Dryland/irrigated land (area)
Dryland crops (area, fertilizer application, FYM application)
Irrigated crops (area, fertilizer application, FYM application)
Fallow (area)

select villages in two logistically suitable locations determined by farmers' willingness to cooperate in the study, most commonly representative soil type, and general socio-economic conditions of these villages representative of the regions. The initial survey covered demographic and agricultural information (Table 2), and was carried out with the support of local non-governmental organizations (NGOs) and government organizations. Based on the survey, a remote village Nusikottala and a road-connected village Krishnamreddypally in the Anantapur district for the groundnut-based system, and Amisthapur, Elkicherla, Seripalli villages of Bhootpur mandal in the Mahboobnagar district for the sorghum-based system were selected as locations for the nutrient balance study.

In the Mahboobnagar district, a sample group of 76 farmers from three villages were surveyed and stratified (Fig. 1) according to farm size (Bansil, 1990) as small-holders (<2 ha) about 35% (26 farmers), medium-holders (2–10 ha) about 61% (45 farmers), and large-holders (>10 ha) about 4% (three farmers) of the surveyed group of farmers. Accessibility versus non-accessibility to irrigated land was also considered in sub-grouping the farmers. All the large-holders possessed irrigated land, while 82% (37 farmers) of the medium-holders and 39% (10 farmers) of the small-holders owned irrigated land. Farmers who owned irrigated land generally possessed more resources to invest in agriculture, including applying FYM to irrigated crops. Within the total sample surveyed, 53 farmers were identified for further study. Farmers thus selected for each cropping system were directly proportional to the percentage of farmers showing preference to the particular cropping system in the main sample (Table 3). The nutrient balances of the same fields were determined in the second season regardless of the crop. For the groundnut-based system

Table 3
Area and proportion of crops in the sorghum- and groundnut-based cropping systems (sample group) in 1994/1995

	Mahboobnagar		Anantapur	
	ha	%	ha	%
Sorghum	43.4	28		
Sorghum/pigeonpea intercrop	8.5	5		
Castor	65.9	42		
Cotton	8.7	6		
Groundnut	5.5	3	235.5	87
Groundnut/pigeonpea	–	–	29.7	11
Sunflower	4.9	3		
Maize	1.2	1		
Horsegram	0.8	1		
Finger millet	1.6	1		
Fallow/others	8.1	5	5.4	2

in Anantapur, the selection of farmers and fields followed similar criteria with the exception that exposure to agricultural extension activities from the research project of Agricultural Research Station, Anantapur was used as an additional selection criterion (Fig. 1). In the Anantapur district, 45 of 56 farmers surveyed were stratified from two villages according to the criteria already explained. The whole survey sample comprised 35% (20 farmers) small-holders (without access to irrigation), 43% (24 farmers) medium-holders, and 22% (12 farmers) large-holders farmers. The organogram in Fig. 1 should also include branching on the right hand side boxes, but this was omitted due to lack of space.

2.3. Soil sample collection and analyses

An initial soil sample consisting of 10 cores per field, at 15 cm soil depth as one layer in the profile, was taken as a composite sample in both years before the beginning of the rainy season, as the field sizes are small and relatively uniform. In the first year, the full profile depth was only sampled in selected fields. In the second year, all fields were sampled to the depth of the murram layer (semi-weathered stratum). The soil samples were analyzed in the ICRISAT central analytical services laboratory for mineral N content (Keeney and Nelson, 1982), available P content (Olsen and Sommers, 1982) and exchangeable K (Thomas, 1982) as per standard procedures.

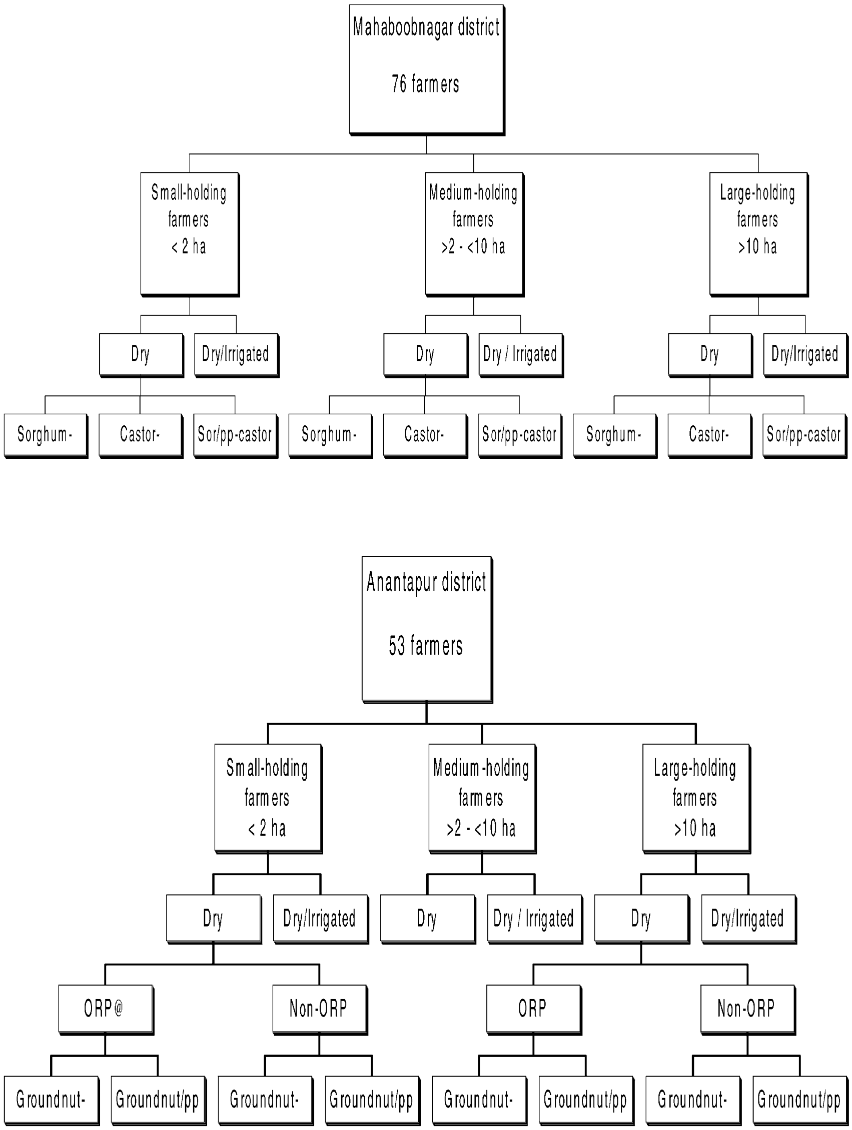

Fig. 1. Systematic selection of farmers for nutrient balance studies in Mahboobnagar and Anantapur districts of Andhra Pradesh, India during 1995–1997. @ Operational Research Project.

2.4. Nutrient input and output measurements

We attempted to establish a partial nutrient balance for nitrogen, phosphorus and potassium for the two cropping systems in the seasons 1995/1996 and 1996/1997. We identified the conceptualized five inputs (mineral fertilizers, organic manure, atmospheric deposition, biological N fixation, sedimentation), and five outputs (harvested product, residue removal, leaching, gaseous losses, water erosion) for an ideal nutrient balance study. Of these factors, we measured nutrient application with mineral fertilizers, organic manure, biological nitrogen fixation through nodulation, and nutrient removal with harvested products and residue removal. Inputs from deposition and sedimentation were not measured, nor were outputs including leach-

Table 4
Questions in the crop nutrient input/output survey

Field identification
  Farmers name, survey number, extent of area of the field
Field history
  Previous season crop, economic yields, straw quantities removed
  Previous season applied manure type, quantity, fertilizer quantity applied, type
Cropping system details (current season)
  Crop 1, cultivar, seed rate, sowing date
  Crop 2, cultivar, seed rate, sowing date
Input details
  1. Organic cakes/manures
    FYM application: source, quantity, and date of spreading
    Organic cakes/concentrates: source, quantity, and date of spreading
  2. Inorganic fertilizers
    Fertilizer type, quantity, and date of application, method of application
  3. Bio-fertilizer application
    Crop applied, rhizobium strain, dosage, seed quantity treated
Outputs
  Crop yields recorded, straw or fodder quantities removed

Table 5
Natural abundance of ^{15}N in nodulating (TMV-2) and non-nodulating (Nonnod) groundnuts, and estimates of %N_{dfa} of TMV-2 grown in farmers' fields of Anantapur district, Andhra Pradesh, India, during the rainy season 1996

Farm-ID no.	δ^{15}N (‰)		%N_{dfa} based on δ^{15}N method
	TMV-2	Non-nodulating	
1	1.20	3.13	47.2
2	1.40	3.93	52.1
3	2.60	5.87	48.1
4	0.73	2.77	50.5
5	1.27	3.30	46.8
6	0.97	4.23	63.7
7	1.23	5.77	64.6
8	0.67	2.60	54.4
9	0.93	2.90	49.8
10	1.83	5.20	52.1
11	1.90	6.13	60.9
12	0.37	1.27	41.7
13	0.97	2.60	46.6
14	1.47	4.57	55.6
15	1.47	6.60	65.1
16	1.43	3.50	46.9
17	0.80	2.93	54.8
18	1.67	4.90	55.9
19	1.47	3.67	48.2
20	1.33	3.93	53.5
Mean	1.29	3.99	52.9
Range	0.37–2.60	1.27–6.60	41.7–65.1

ing, gaseous losses, water erosion at field level due to financial limitation in measuring these parameters accurately. Reliable estimates of these variables could not be made due to a lack of research data from India.

During both cropping seasons, at the beginning of the season and at harvest, we collected plot-specific input data from individual farmers through regular contact and survey (Table 4). This was done with specific reference to the number of the plot, extent of land, quantities of FYM, sheep penning, organic cakes, mineral fertilizers applied, and estimation of BNF by the ^{15}N natural abundance method (Yoneyama et al., 1990) for groundnut in Anantapur (Table 5). In case of pigeonpea, BNF measured by the ^{15}N natural abundance method (Kumar Rao et al., 1996), at the Regional Research Station, Palem, in Mahboobnagar district was used, as it was not possible to make these observations in farmers' fields. However, the farmers' fields under study were in close proximity to this research station and the weather and soils were more or less similar in nature. Outputs were calculated from harvested crop samples of grain and fodder. Nutrient inputs and crop yields for the preceding cropping season were also obtained in order to understand the effect of application of large quantities of FYM by several farmers. Samples of organic manure were taken and analyzed for NPK content as for plant samples. In the case of mineral fertilizers, the fertilizer type was determined through farmers' interviews. NPK content of these fertilizers was based on the manufacturers' grading.

For the sorghum-based system, the number of fields harvested was not identical to the number of fields and crops selected initially for the study, since farmers frequently changed their plans according to weather conditions. In addition, crop failure later in the rainy season due to intermittent drought, disease or pest pressure prevented normal crop harvest in some cases. This may account for the relatively higher percentage of fallow mentioned in the official crop statistics compared to the percentage of planned fallow we observed in our initial survey. However, there were no deviations from planned measurements in the case of groundnut-based systems.

Crop nutrient removal was generally determined through crop samples. Four sub-samples per field were taken. Each sub-sample consisted of two rows of 2 m length. In some cases it was not possible to obtain yield data, since farmers had already harvested the crop. In these cases, farmers supplied the yield information and a sample of the plant material was taken for mineral nutrient analysis. Grain and vegetative parts were analyzed separately. Plant N and P contents were determined with a Technicon® auto analyzer and K content with an atomic absorption spectrophotometer after digestion of plant samples in conc. H_2SO_4 containing 0.5% Se at 360 °C.

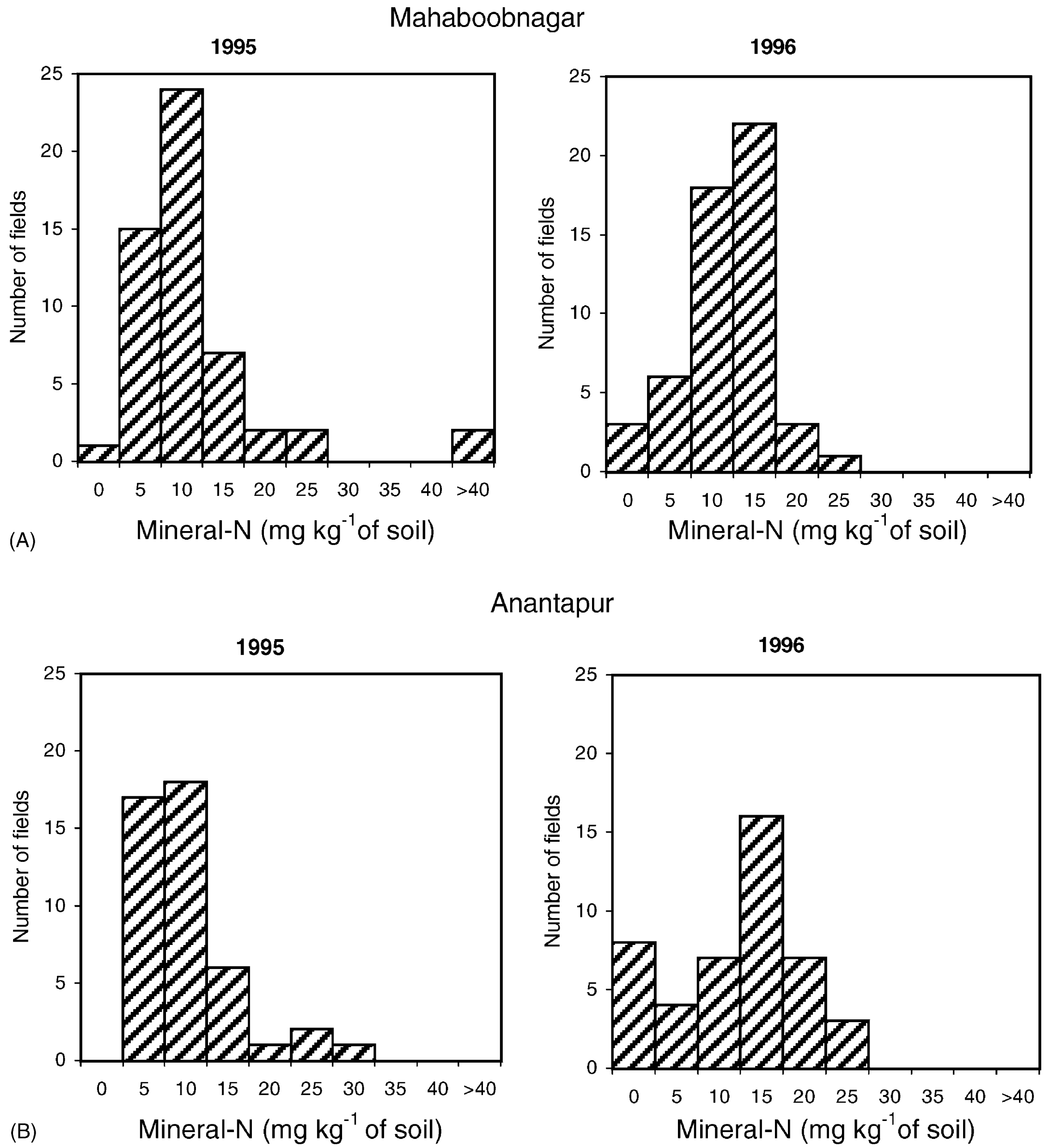

Fig. 2. Mineral N content before the beginning of the cropping season in the topsoil (0–15 cm) of fields selected for nutrient balance studies in (a) Mahboobnagar district (53 fields) and (b) Anantapur district (45 fields).

3. Results

3.1. Soil nutrient content before the beginning of the rainy season

3.1.1. Mineral nitrogen

The mineral N content before the beginning of the rainy season was in both years and locations surprisingly high. The most frequent topsoil N content (0–15 cm) was 5–10 mg N kg^{-1} in 1995 and 10–15 mg N kg^{-1} in 1996 (Fig. 2). The distribution of the Mahboobnagar data resembled a normal distribution but the Anantapur data showed greater frequencies at lower mineral N contents. The hypothesis that a greater proportion of legumes in the cropping system might lead to higher mineral N contents in the topsoil of the Anantapur fields than in the Mahboobnagar fields was not confirmed. However, mineral N content in the topsoil says little about soil N supply. The mineral N content in the soil profile provides more information (Fig. 3). To obtain this information, the average mineral N content of each layer and for each

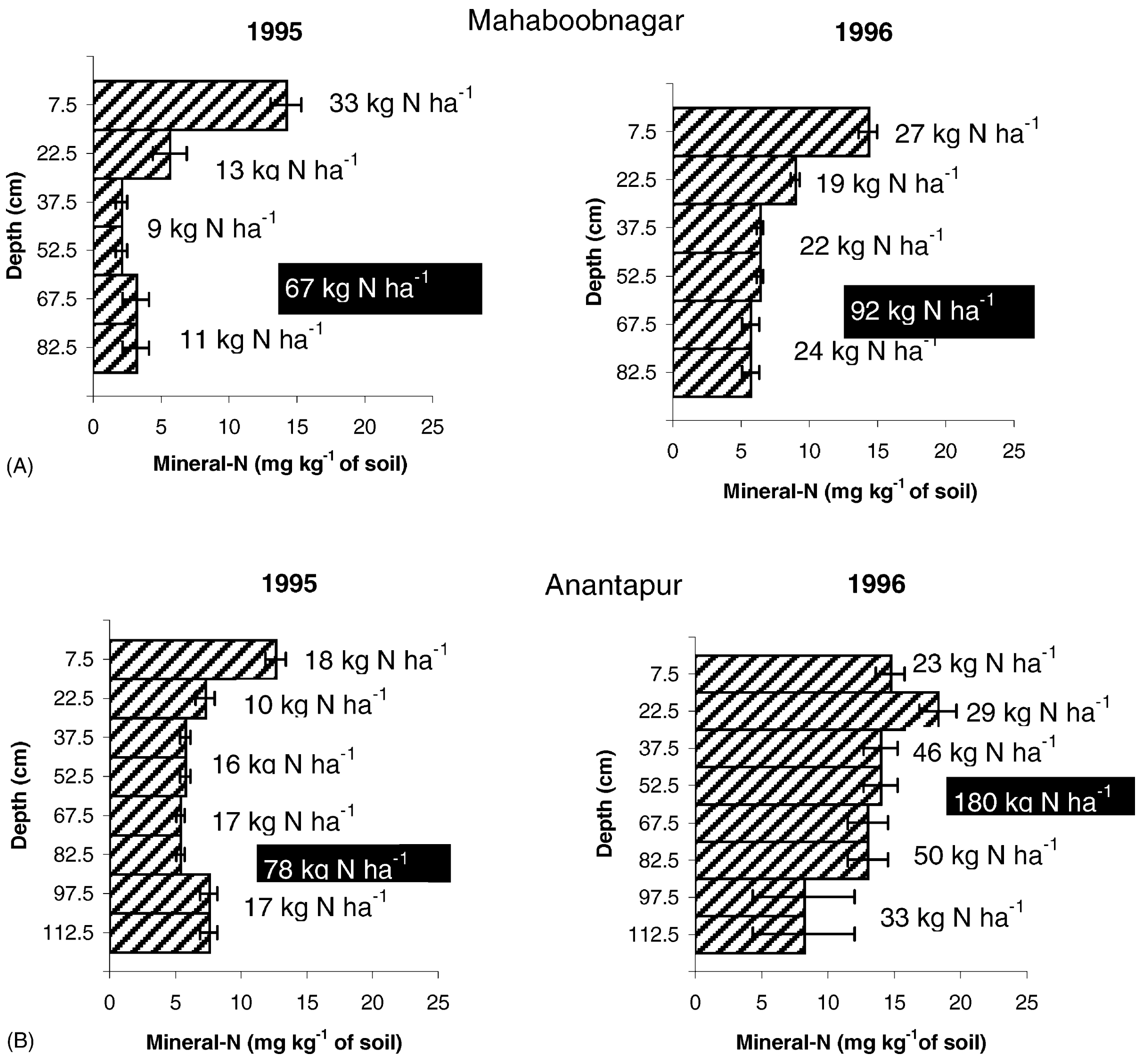

Fig. 3. Average mineral N content before the beginning of the cropping season in the soil profiles of fields selected for nutrient balance studies in (a) Mahboobnagar district (53 fields) and (b) Anantapur district (45 fields). Horizontal bars indicate S.E. of mean.

location was calculated from the individual values for each field. The values for the different layers were calculated from different numbers of replicates due to the differences in sampling depth. Small standard errors demonstrate that the number of replicates was sufficient even at lower depth. It also demonstrates, that despite the differences in topsoil N content of individual fields, the large number of replicates allowed calculation of a mean concentration for the topsoil which adequately described the most frequently observed topsoil mineral N content. Nevertheless, the average N contents in Fig. 3 and, particularly, the summation of the amounts of nitrogen have to be considered with care, since they depict a

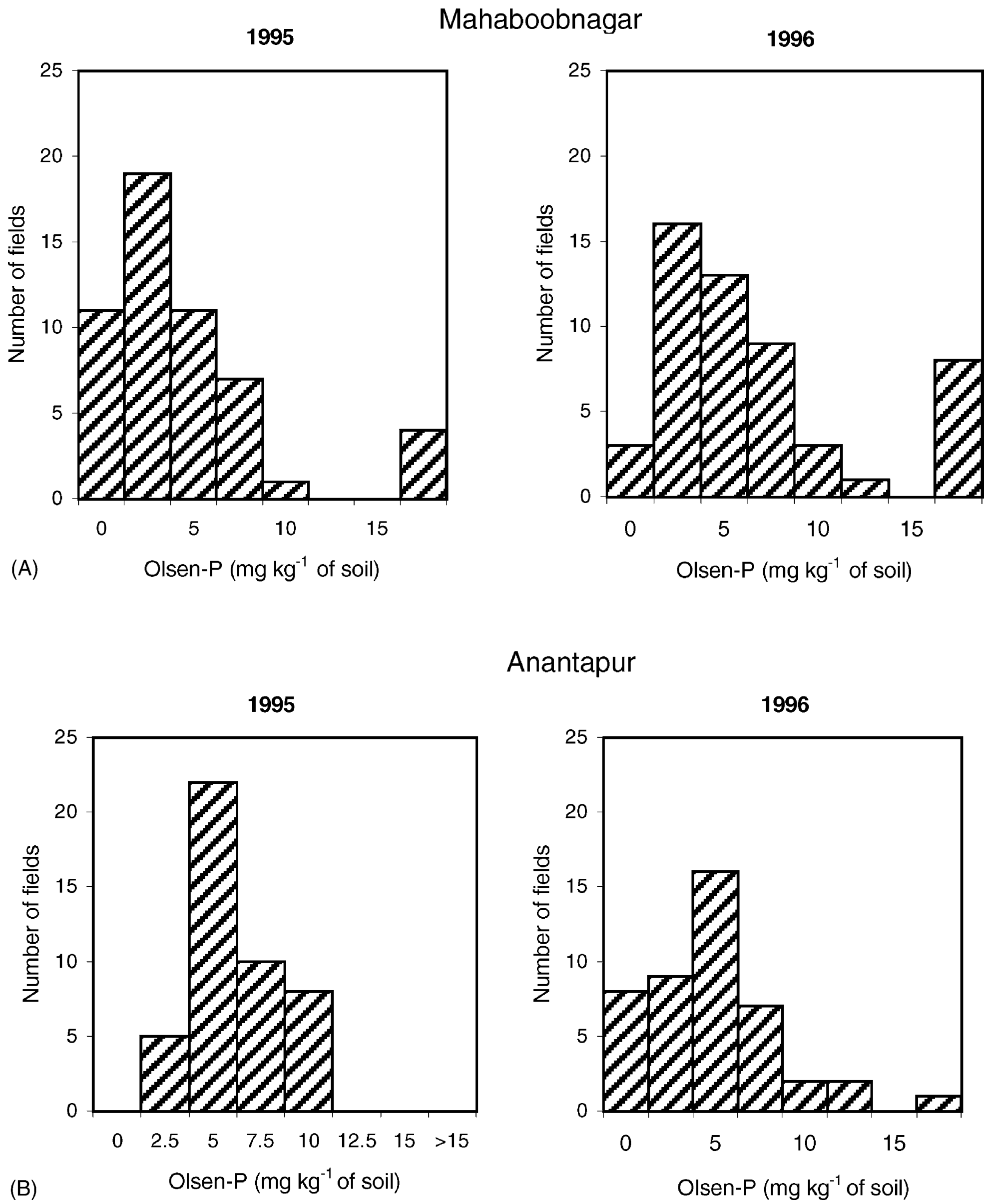

Fig. 4. Available P content (Olsen-P) in the topsoil (0–15 cm) of fields selected for nutrient balance studies in (a) Mahboobnagar district (53 fields) and (b) Anantapur district (45 fields).

soil profile up to 90 cm in Mahboobnagar and up to 120 cm in Anantapur. In many fields, the soil was considerably shallower.

3.1.2. Available phosphate

Available P (Olsen and Sommers, 1982) was in the majority of fields below 10 mg P kg^{-1} in the topsoil (0–15 cm), that is, for most crops the threshold value for sufficient P supply (Fig. 4). The largest number of fields had a P content of 5–7.5 mg P kg^{-1} in Anantapur, and 2.5–5.0 mg P kg^{-1} in Mahboobnagar. However, in both years a number of fields in Mahboobnagar had Olsen-P contents higher than 15 mg P kg^{-1}.

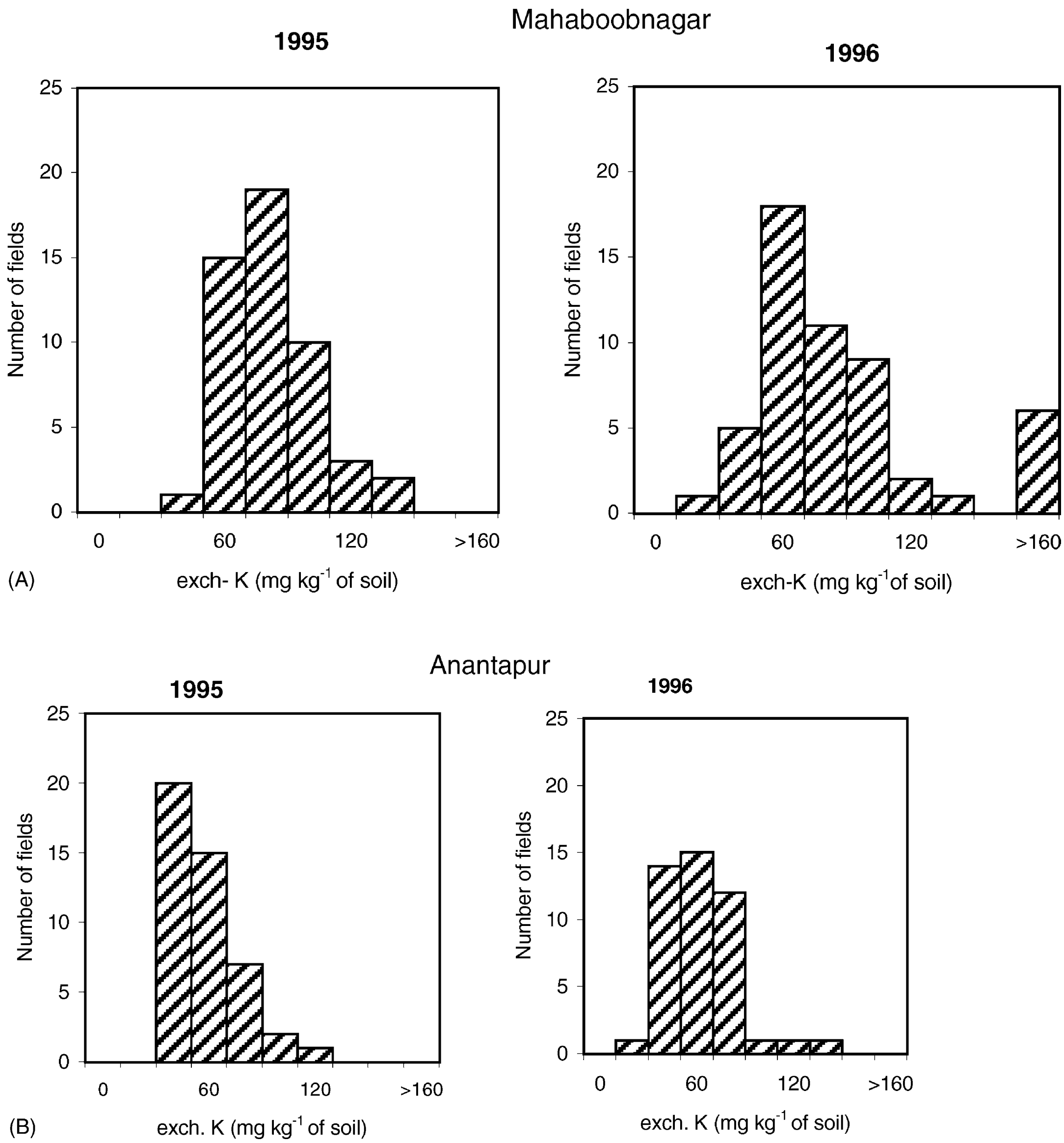

Fig. 5. Exchangeable potassium content (exch. K) in the topsoil (0–15 cm) of fields selected for nutrient balance studies in (a) Mahboobnagar district (53 fields) and (b) Anantapur district (45 fields).

3.1.3. Exchangeable potassium

Exchangeable K contents indicated that the potassium supply was sufficient in most fields. In Mahboobnagar (Fig. 5a), most fields had a medium K status (50–130 mg K kg^{-1}). Low K contents (<50 mg K kg^{-1}) were only found in five fields in 1996. High K contents (>130 mg K kg^{-1}) were found in six fields in 1995 and nine fields in 1996, respectively. In Anantapur (Fig. 5b), most fields had a medium K status. However, six fields had a low K status in both years and one had a high K status in 1996.

3.2. Nutrient inputs

Nitrogen inputs in sorghum-based 2 years rotations ranged between 87 and 146 kg N ha^{-1}. These larger variations in input application resulted from varied inclusion of castor, cotton or sorghum intercropped with pigeonpea in the rotation. This is a clear indication of farmers' preference to apply increased inputs to commercial and highly remunerative crops even in dryland systems. Another interesting aspect is that larger amounts of N (>75 kg N ha^{-1}) in this input pool were derived from FYM application (Fig. 6). The castor crop was an exception in receiving relatively low (45 kg N ha^{-1}) FYM application. The maize crop also received farmers' attention in terms of N inputs as the market-demand and price for grain as well as fodder was attractive. The sole sorghum rotation received very little attention for N input. As groundnut is a leguminous oilseed crop, farmers generally apply less N as part of a complex fertilizer (for example diammonium phosphate, 18 N–46 P_2O_5–0 K), and the remaining N in the form of FYM. Hence most of the applied N (20 kg ha^{-1}) for the groundnut is from FYM, amounting to 74% of the applied N.

3.3. Crop yield and nutrient output

The large rainfall and particularly rainfall distribution differences between years would contribute to the yield differences observed between years (Table 6). In 1996, early rains followed by intermittent drought caused failure of the first sorghum planting in many fields. Later plantings of sorghum suffered due to shoot fly, which is typical for this region. Other slower growing crops like castor, cotton and pigeonpea suffered less from drought and late planting because their initial water requirements were lower and due to their deeper root systems.

In the groundnut-based system, the yield differences between the two sample villages and the two

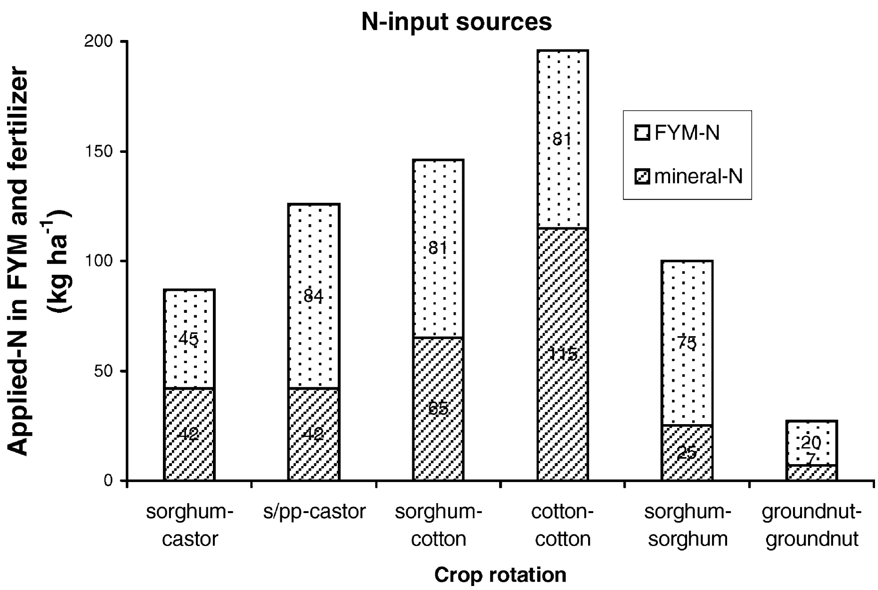

Fig. 6. Nitrogen inputs in the form of fertilizer N and farmyard manure into different rotation for 2 years.

Table 6
Average crop yields (cotton: lint and seed; groundnut: pods) in the sorghum-based (Mahboobnagar district) and groundnut-based cropping system (Anantapur district) during 1995–1996

Crop	1995			1996		
	No. of fields	Yield (kg ha^{-1})	S.E.[a]	No. of fields	Yield (kg ha^{-1})	S.E.
Sorghum	16	2079	329	14	618	67
Castor	20	331	65	15	459	46
Cotton	8	428	81	11	499	53
Pigeonpea	14	449	110	4	403	216
Maize	1	0	NA	2	1977	494
Groundnut	45	1427	66	44	1158	59

[a] Standard error of the mean.

experimental years were small, indicating greater yield stability compared with the sorghum-based system. However, for the large number of replicates (45 and 44), the high standard error showed that the yield differences between individual fields were large.

The crop or cropping system with the highest N uptake was the sorghum/pigeonpea intercrop. However, part of this nitrogen was from atmospheric nitrogen fixation. Of the crops relying only on applied N or soil N, cotton in 1995 and maize in 1996 had the highest N uptake. Phosphorus uptake was highest in the sorghum/pigeonpea intercrops followed closely by the sorghum sole crops. The sorghum/pigeonpea intercrops also had the highest K uptake, which was only surpassed by maize in 1996.

3.4. Nutrient balances

From the results, we estimated overall nutrient balances in some of the cropping systems at farmers' field level. In a sorghum–castor rotation, the N input was 87 kg ha^{-1}, as against an output of 77 kg N ha^{-1}, indicating a net annual gain of +10 kg ha^{-1} (Fig. 7). As N losses were not estimated in this study, the +10 kg N ha^{-1} may not indicate the correct N balance. For P and K, which are less susceptible to loss, the estimates clearly reveal positive P and negative K balances in the cropping systems. With an improved sorghum/pigeonpea–castor system, the nutrient balances of N (+2), P (+22), and K (−38) kg ha^{-1} were estimated (Fig. 8). The positive balance for N included an estimate for BNF of intercropped pigeonpea at 47.4%N_{dfa} (equal to %N derived from air) (Kumar Rao, personal communication), and an uptake of 41 kg N ha^{-1} resulted in a minimal (+2 kg N ha^{-1}) positive N balance. Adu-Gyamfi et al. (1998) reported better N fixation (%N_{dfa}) percentage of 59.2% by pigeonpea intercropped with sorghum on an Alfisol at ICRISAT, Patancheru. This difference in BNF of pigeonpea is anticipated considering the expected better-managed soils and well-distributed rainfall conditions at the experimental site as against farmers' fields in the Mahboobnagar district. Nutrient balances for the mirror images of the two systems, namely castor–sorghum (+45 kg N, +35 kg P, +1 kg K ha^{-1}), as well as the castor–sorghum/pigeonpea (+58 kg N, +44 kg P, +32 kg K ha^{-1}) were positive. But these NPK balances seems to differ due to seasonal variability. Over a longer

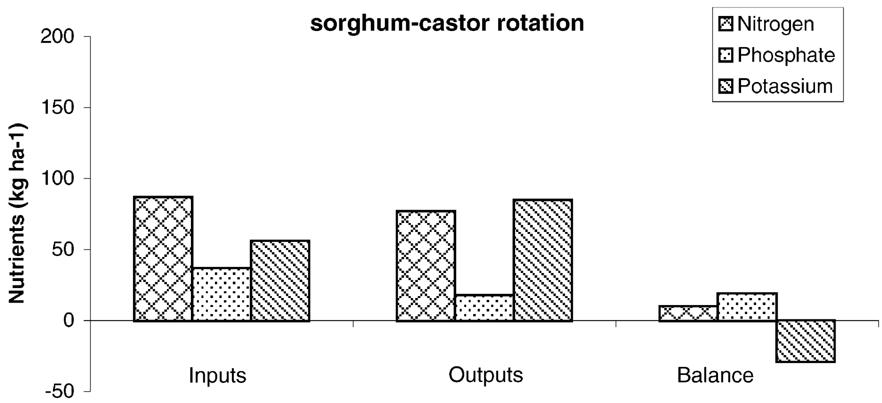

Fig. 7. Soil–plant NPK balances observed in farmers' fields with a 2 years sorghum–castor rotation as managed by farmers in Mahboobnagar district of Andhra Pradesh, India during 1995–1996 and 1996–1997 cropping seasons.

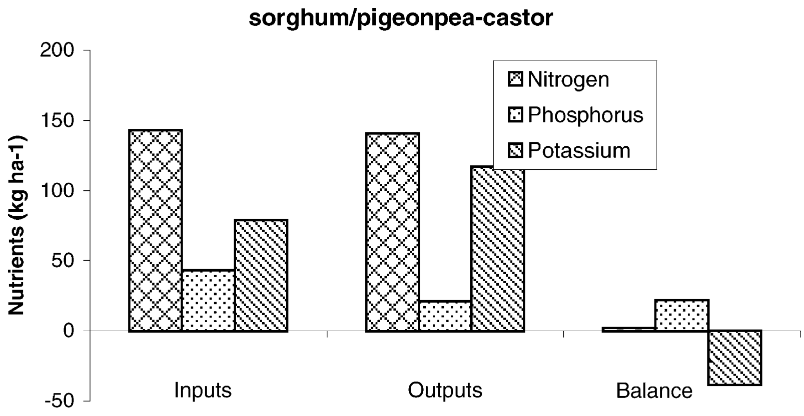

Fig. 8. Soil–plant NPK balances observed in farmers' fields with sorghum/pigeonpea–castor as managed by farmers in Mahboobnagar district of Andhra Pradesh, India during 1995–1996 and 1996–1997 cropping seasons.

period, we observed similar nutrient balances in a long-term cropping systems experiment at ICRISAT in Patancheru, India (Rego and Nageswara Rao, 2000).

The continuous cropping system of sole groundnut was on average positive for P (+37 kg ha^{-1}) and negative for K (−20 kg ha^{-1}) (Fig. 9). For N, when an estimate of BNF was not included, the balance was negative (−111 kg ha^{-1}). However, our observations indicate that $\%N_{dfa}$ in 20 farmers' fields ranged between 42 and 65%, with an average of 53% of the total-N uptake. Under these circumstances, the N balance would be negative (−26 kg ha^{-1}). In order to achieve a positive N balance, BNF would need to be >68% of the total uptake. The soil analysis data from these farmers' fields indicated limited build up of soil N in spite of groundnut monocropping for more than 40 years. Moderately efficient BNF in the farmers' fields as well as very low use of fertilizer N may be the reasons for poor accumulation of soil N. There is scope to increase BNF to 92% (Peoples and Herridge, 1990).

A 2 years rotation of cotton and sorghum/pigeonpea intercrop indicated reasonably high positive balances of N and P as indicated by +129 kg N ha^{-1} and

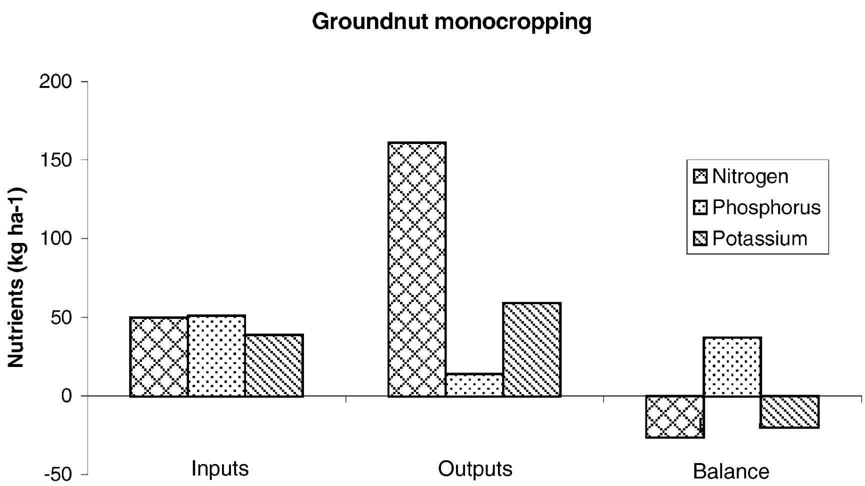

Fig. 9. Soil–plant NPK balances observed in farmers' fields with groundnut monocropping as managed by farmers in Anantapur district of Andhra Pradesh, India during 1995–1996 and 1996–1997 cropping seasons.

$+78$ kg P ha^{-1} mainly due to application of fertilizer inputs to cotton. Farmers in this region grow medium duration (135–150 days) cotton and castor cultivars. Farmers tend to apply more than the recommended quantities of fertilizers and FYM to both cotton and castor. In addition, during the later stages of crop growth, moisture stress may also affect the uptake of nutrients by these crops in this region. Nutrient residues thus remain in the soil for next season, which helps sequential crops in the rotation. Potassium imbalance has emerged as a common constraint in most cropping systems. The intensity and the extent of the imbalance will be revealed in time based on K supplying capacity of the soil.

4. Discussion

The two villages in this study represent drier regions of Telangana and Rayalaseema, Andhra Pradesh, a less endowed SAT region in India. This study methodically focused on determining nutrient balances in two cropping systems and farmer-oriented nutrient management practices. Unlike Brouwer and Powell (1998) who studied nutrient flows within-plots, our study encompassed cropping system as a superset, intersecting several farms with plots (fields) as subsets, within the AER. Van den Bosch et al. (1998) also adapted a similar methodology to measure nutrient flows and balances, with the exception that they considered a farming systems approach to obtain full and partial nutrient balances for individual activities and for entire farms in three districts of Kenya. These farms were contiguous, larger in size and contained diverse activities. While Harris (1998) also adapted the farming systems approach to estimate nutrient balances on similar farms in Nigeria, he restricted the measurement of inputs and outputs to those that farmers know and manipulate. However, in our study region, the individual farmers owned scattered small landholdings. Hence, it was necessary to obtain correct and complete datasets on field-specific nutrient balances from farmers using a cropping system approach rather than a farming system approach.

Among several cropping systems of the regions, nutrient balances were studied for traditional and intensively cultivated improved systems. The entire study was conducted on dryland cropping systems, although due consideration was given in selecting farmers who had access to irrigation. Hence the methodology used discriminated between nutrient balances in a dryland farming situation from those under irrigation in the same cropping system elsewhere. We feel that up-scaling of this information will be useful and relevant to farmers in this AER. Our methodology could also be used for integration of data at AERs, and up-scaling from all AERs to the national scale and should provide more authentic information on nutrient balance than the methodologies adapted by Biswas and Tewatia (1991).

All the three major nutrients were studied individually for their balance in the soil–plant system of each crop rotation to be of more use to farmers in managing soil nutrition efficiently. N losses due to leaching in farmers' fields were not studied, although these are considered to be higher in lighter Alfisols. Van den Bosch et al. (1998) speculated that leaching losses of 0–22% was a reasonable range for inorganic fertilizers, although losses depended on factors such as time and mode of application in relation to rainfall in the African context.

As already mentioned, nitrogen losses reported from dryland systems were 30% on shallow Vertisols and Alfisols (Moraghan et al., 1984; Katyal, 1988). Most importantly, the mineralized-N observed before the beginning of the season was as much as 46 kg ha^{-1} in both years in Mahboobnagar, and varied between 28 and 52 kg ha^{-1} in Anantapur farmers' fields. This was not considered as an input into the system for two reasons. Firstly, mineral N is exposed to leaching losses beyond the root zone within 30 days of the onset of rainy season, when 40–50% of the total rain falls in this region. Under these conditions, the loss of mineralized-N below the root zone is high (Vlek and Vielhauer, 1994). De Datta et al. (1990) observed disappearance of 91 kg ha^{-1} of NO_3-N from a 30 cm soil layer in unfertilized plots when cumulative rainfall within a week after planting exceeded 492 mm. Secondly, crops like castor, cotton, and pigeonpea in this study are initially slow growing and are unlikely to utilize the mineral N available at the time of sowing. Erosion losses are also higher in this environment due to poor soil structure and high intensity rains, but the number of runoff events is generally small. However, we assume that the effect of erosion on P and K balances may be higher based on the movement of surface soil. As there is very little information on these losses, it is difficult to estimate the extent of nutrient loss through soil erosion. It was observed from the data that farmers in both districts applied large quantities of FYM on bare soil before the onset of monsoon when the temperatures are generally higher, thereby inducing higher losses of N by volatilization.

Nutrient balance in sorghum/pigeonpea–castor system showed a minimal positive N balance. N_2 fixation by pigeonpea was estimated at 19.4 kg N ha^{-1}, and the removal by harvested biomass was 41 kg N ha^{-1}, resulting in a net negative N balance (−21 kg N ha^{-1}) with intercropped pigeonpea alone due to removal of legume crop residue from the field. Wani et al. (1994) recalculated the net N balances from Peoples and Crasswell (1992) assuming that legume crop residues are generally removed from the system, and indicated that different maturity groups of pigeonpeas mine soil N in a range of 20–49 kg N ha^{-1}, besides fixed N. However, Sheldrake and Narayanan (1979) observed a considerable amount of leaf fall of a medium duration pigeonpea to soil that amounted to an addition of 30–40 kg N ha^{-1}. Rego and Seeling (1996) reported increased soil total-N and increased N uptake in the range of 35–47 kg N ha^{-1} by the succeeding sorghum crop with different pigeonpea-based cropping systems, even with the removal of harvested residues from the system. Farmers on average applied 84 kg N ha^{-1} (i.e. 67%) through FYM to this system along with fertilizer N. Application of FYM would probably help immobilizing the soil N at the beginning of the season, which would otherwise be lost as both crops in the system (sorghum and pigeonpea) are initially slow growing. As sorghum competes for soil N and forces pigeonpea to fix N_2 from nature, this seems to be a good intrinsic N management strategy in this cropping system.

Measurements of biological N fixation by groundnut in different farmers' fields indicated $\%N_{dfa}$ in the range of 42–65%, which was better and narrower compared to 22–92% reported by Peoples and Herridge (1990). This moderate fixation level may be attributed to conditions of low soil N, low fertilizer N input, and greater FYM application to the groundnut system. Since the study comprised a cross-section of farmers who had applied fertilizers as well as FYM, based on their own perceptions and available resources, the data obtained was of greater value for policy makers.

We calculated mined soil nutrient replenishment costs for each cropping system based on the market prices of inorganic fertilizers at Rs. 222 (US$ 4.75) for supplementing K in the sorghum–castor system, Rs. 396 (US$ 8.5) for replenishing N and K in the groundnut system, and Rs. 309 (US$ 6.5) for replenishing N and K in the sorghum/pigeonpea–castor system. However, variability in nutrient balances due to seasonal variation and resultant crop production, would be narrowed down if a longer duration study was conducted with similar methodology. Besides, applying systems simulations models like Agricultural Production Systems Simulator (APSIM) or Decision Support System for Agro-Technology Transfer (DSSAT) would help to determine the long-term effects of different cropping systems and the resulting nutrient balances with a particular cropping systems.

5. Conclusions

This study provides factual information on nutrient balances specifically for different cropping systems in farmers' fields, which can be generalized for the region. Inefficient BNF in groundnut monocropping over a long period suggests that more efficient BNF rhizobium strains could make a contribution to that region. Measuring N losses precisely within different cropping systems in farmers' fields by applying isotope ^{15}N would help in understanding N dynamics in this environment. As FYM is the major source of applied N, mechanisms to reduce losses of N during manure production and field application needs further study to achieve nutrient balances at lower cost. Phosphorus inputs met the crop requirements in most of the cropping systems studied. K and N application should be recommended in dryland cropping systems either through FYM or fertilizer inputs to reduce nutrient mining for sustaining crop productivity on degraded soils. Positive nutrient balances in maize- and cotton-based cropping systems are attributed to farmers' preference for fertilizer application to commercial crops. Creation of databases, maintenance of crucial datasets and dissemination of information on nutrient balance studies in such cropping systems at the AER scale would be a useful guide to policy makers, extension specialists and farmers alike in dealing with nutrient management of individual cropping systems.

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