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Nutrient Management for Sustaining Productivity of Sunflower-Based Cropping Sequence in Indian Semiarid Regions

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ABSTRACT

A comprehensive long-term study (2006–2010) was undertaken to develop a balanced and integrated nutrient supply system for sunflower-based cropping sequence considering the efficient utilization of residual and cumulative soil nutrient balance along with added fertilizers by the crops grown in rotation. The fertilizer application was done in potato and sunflower while greengram was raised as such on their residual effect. Significant response in yield was observed with 150% of the recommended nitrogen, phosphorus and potassium (NPK) or inclusion of farmyard manure (FYM) with the recommended NPK in the cropping sequence indicating 6.2–7.0% gain in system productivity over the existing recommendations. Each additional unit of P and K nutrition prompted system productivity by 18.9 and 11.0 kg kg^{-1} of applied nutrient, respectively. Apparent yield decline was observed in K and PK omission plots to the extent of 15.8 and 27.4% in potato, 10.5 and 23.9% in sunflower and 4.2 and 8.3% in greengram, respectively, compared to the recommended fertilization. The superiority of the FYM along with the recommended NPK (potato/sunflower) was evident on the overall profitability and sustainability of the system, highlighted by the significantly higher productivity (7.16 t SFEY ha^{-1}), sustainability yield index (SYI; 0.76), production efficiency (PE; 27.85 kg SFEY ha^{-1} day^{-1}) and net returns (2520 USD ha^{-1}) with a B:C ratio of 2.91. Apparent change in potassium permanganate ($KMnO_4$)-N was negative in all the treatments while N and P balance was positive with 150% NPK fertilization. Nutrient uptake exceeded the replenishment with 100% NPK application and maintained net negative soil nutrient stock for all the primary nutrients, indicating the need for revalidation of the existing recommendations in the system perspective. Conspicuous improvement in residual soil fertility in terms of maximum buildup of soil organic carbon (14%) and enhancement in soil $KMnO_4$-N (4.2%), Olsen-P (19.4%), ammonium acetate (NH4OAc)-K (5.8%) and dehydrogenase enzyme activity (44.4%) was observed in FYM-treated plots over the initial values. The study suggested that the inclusion of legumes and FYM application with the recommended NPK in potato-sunflower cropping sequence will sustain the system's productivity through the efficient use of nutrients, enhanced microbial activity and improved soil health while combating escalating prices of fertilizers as well as environmental issues in the Indo-Gangetic plains of India and similar environments.

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Nutrient balance; productivity; profitability; sunflower; sustainability

Introduction

Nutrient management on farmlands plays an important role in crop production and environmental protection (Prasad 2009; Tilman et al. 2002). Oil-bearing crops are energy-rich and demand heavy

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nutrition for optimum production. Although the use of chemical fertilizers is the fastest way of counteracting the pace of nutrient depletion from soil, their increasing cost, adverse impact on the environment and timely availability deter the farmers from using the required nutrients in balanced proportions (Babu et al. 2015; Suryavanshi, Sudhakara Babu, and Suryawanshi 2015). On an average, only 52.5 kg ha^{-1} nutrients nitrogen, phosphorus and potassium (NPK) are applied in oilseeds as against the 140 kg ha^{-1} for rice and 160 kg ha^{-1} for wheat (Tiwari 2008). Imbalanced fertilization and/or inadequate replenishment of native soil nutrient reserves has resulted in the emergence of multi-nutrient deficiencies, decline in factor productivity of applied nutrients and concomitant reduction in the productivity of several crops including oilseeds in India (Hegde and Sudhakara Babu 2009; Suresh et al. 2013). The average productivity of oilseeds in India is around 1.0 t ha^{-1}, which is far below that of the developed countries (2.5–3.0 t ha^{-1}) and the world average (1.9 t ha^{-1}) (Damodaran and Hegde 2010). An adequate nutrient supply system through integrated nutrient management with more reliance on low-cost, on-farm/local resources (Lelei, Onwonga, and Freyer 2009) and reduced dependence on chemical fertilizers (Davari and Mirzakhani 2009; Kannan et al. 2013) is essential for regulated nutrient supply and reduced losses, besides lowering costs, improving nutrient-use efficiency (Sheoran et al. 2016b) and soil biodiversity (Sharma and Banik 2016; Subba Rao et al. 1998).

The fertilizer need of a crop in a given cropping system is mainly a function of characteristics of a preceding crop, nutrient-supplying capacity of the soil and kinds and quantities of manure and fertilizers applied. Potato (*Solanum tuberosum*)-sunflower (*Helianthus annuus*) cropping sequence has become an established cropping system in the Indo-Gangetic plains of India where virus-free conditions provide a favorable environment for higher productivity of potato, particularly seed potato; spring season sunflower offers the best environmental conditions for higher per day productivity, thus making it one of the most profitable cropping systems in the country. It is an input-intensive system, especially fertilizers (Thind et al. 2007). Potato requires the liberal application of primary nutrients owing to its shallow rooting pattern. Sunflower grows luxuriantly to complete different phenophases within a short time frame and makes efficient use of applied and residual nutrients due to its deep-rooting growth habit. Continuous cropping with such an exhaustive system results in over-mining of nutrients from soil reserves and may not sustain in the absence of adequate restorative practices. There is need to work out the nutrient requirements of a cropping system as a whole rather than the fertilizer requirements of individual crops in the present-day exploitive agriculture. Furthermore, newly developed plant types draw heavy nutrition and nutrient uptake often exceeds replenishment through fertilizers, adversely affecting soil health. Contribution of legumes in improving nitrogen availability through direct fixation and biomass decomposition and soil physical conditions is well known, thereby enhancing the total productivity of the system (Adu-Gyamfi et al. 2007; Fustec et al. 2010; Lupwayi and Kennedy 2007).

The current blanket fertilizer applications (state or region specific) are gross approximations based on the nutrient requirements of individual crops, ignoring the carryover effect of manures/fertilizers to the succeeding crops. Fertilizer-use efficiency can be increased by adopting appropriate nutrient management strategies based on the cropping system as a whole, rather than individual crops. The fertilizer requirements of the potato-sunflower-greengram cropping system, which is highly productive and one of the most remunerative ones in the country, are highly desired to make the system more productive, sustainable, eco-friendly and more remunerative to indicate the comparative capability in the system's perspective. Hence, an attempt has been made to develop an integrated nutrient supply system for the efficient utilization of residual and cumulative soil nutrient balance along with added fertilizers in sunflower-based cropping sequence.

Materials and methods

Experimental site description

The field experiment was initiated during winter 2006–2007 with potato (October–January/February) as the first crop, followed by sunflower during spring/summer (January/February–May/

June) and greengram during the rainy season (July–September/October) and continued up to 2009–2010 on a fixed plot layout. The experimental site is situated at a research farm of Punjab Agricultural University, Ludhiana (30°56′ N, 75°52′ E, 247 meters above msl), located in the Indo-Gangetic alluvial plains in the state of Punjab, northwestern India. The location represents semiarid, monsoonal climate with an average annual precipitation of 760 mm, 80% of which is received during July to mid-September. Winter and spring seasons remain mostly dry and receive few showers of cyclic rains.

Treatments and crop culture

The soil was well-drained sandy loam (Typic ustipsamment) with pH 8.0 (1:2 soil/water suspension), electrical conductivity 0.21 dS m^{-1}, organic carbon (C) 1.5 g kg^{-1} soil, alkaline potassium permanganate ($KMnO_4$) oxidizable N 50.1 mg kg^{-1}, 0.5 M sodium bicarbonate ($NaHCO_3$) extractable P 6.7 mg kg^{-1} and 1 N ammonium acetate (NH_4OAc) exchangeable K 81.7 mg kg^{-1} soil in soil 0–15 cm deep. The experiment was designed in a randomized block with six treatments (details in Table 3) and three replications and fixed gross plots of 4.8 m x 4.2 m were marked. The fertility treatments were applied to potato during the winter season and to sunflower during the spring season and repeated each year. Green crop was raised as such without any fertilizer application on residual fertilizer effect of nutrient management treatments applied to potato and sunflower. In a farmyard manure (FYM)-treated plot, conventionally prepared well-decomposed FYM (0.90 ± 0.04% N, 0.22 ± 0.04% P and 0.93 ± 0.04% K on dry weight basis) from cattle dung mixed with leftover crop residues was uniformly incorporated 10–15 days prior to sowing. All plots received the same treatment as per layout throughout the period of study.

Total crop growth period (CGP), considered as the time period from sowing to physiological maturity, ranged between 87 and 98 days (mean 91 days, CV 5.3%) in potato, 102 and 111 days (mean 106 days, CV 3.5%) in sunflower and 78 and 82 days (mean 80 days, CV 2.6%) in greengram crop. Greengram crop failed during 2008–2009 due to intense rains immediately after germination, followed by continuous water-logging.

The land preparations were performed mechanically with proper care to avoid mixing of soil from the adjacent plots. All the three crops were grown with assured irrigated facilities and other management practices, including insect-pests, which were followed according to local agronomic practices unless otherwise indicated. The details of agronomic practices and sowing and harvesting schedule are presented in Table 1.

Sampling, determination and calculations

Yield data

The yield data were recorded from the central rows by discarding two external rows of each plot (as borders) and the yield samples were dried to a constant weight and threshed manually to determine the economic yield (tuber or seed) from the net plot, which was then expressed in t ha^{-1}.

Soil and plant analysis

To assess the impact of nutrient management practices on soil fertility, composite soil samples were collected from cultivated soil layer (upper 15 cm) from each experimental unit (plot). These samples were air dried, crushed and passed through a 2-mm sieve to remove any crop residue or other undesirable materials. The samples were analyzed employing standard analytical procedures for soil organic carbon (C) (Walkley and Black 1934), available N (Subbiah and Asija 1956), Olsen's P (Olsen et al. 1954) and available K (Stanford and English 1949). The dehydrogenase activity (DHA) was estimated as per the procedure outlined by Klein, Loh, and Goulding (1971). Plant samples from each plot were also collected at harvest of each crop, oven dried and analyzed for N, P and K concentrations by following the micro-Kjeldahl, vanado molybedo phosphoric acid yellow color and

Table 1. Catalogue of cultivation practices for the field experimentation.

Parameters	Crop		
	Potato	Sunflower	Greengram
Sowing /harvesting schedule			
2006–07	Oct 06/Jan 01	Jan 24/May 10	Jul 12/Sept 28
2007–08	Oct 15/Jan 12	Feb 02/May 24	Jul 25/Oct 15
2008–09	Oct 24/Jan 23	Feb 20/Jun 05	Jul 15/crop failed
2009–10	Oct 16/Jan 22	Feb 12/May 25	Jul 11/Oct 01
Varieties/hybrids	Kufri Chandramukhi/Kufri Pukhraj	PSH 569	PAU 911
Sowing method	Ridge-furrow/Dibbling	Ridge-furrow/Dibbling	Flat/Pora
Spacing (cm)	60 x 15–20 cm	60 x 30 cm	30 cm
Recommended fertilization (kg ha^{-1})* (N:P:K)	187.5:27:52	60:13:25	–
Fertilizer scheduling	Full P and K and half N at sowing and remaining N at the time of earthing-up.	Full P and K and half N at sowing and remaining N one month after sowing.	–
Weed control	Pendimethalin @ 0.75 kg ha^{-1} (Pre-em)	2 weedings; three and six weeks after sowing	1 weeding 25–30 days after sowing
Earthing-up	One month after sowing	Knee height stage	–

**variable as per the treatments in Table 3*

flame photometric methods, respectively. Nutrient uptake was estimated by multiplying the nutrient concentration of plant samples with their respective dry weight and summed up to obtain the total uptake. Apparent NPK balance was determined as the difference between nutrients added through fertilizers as well as FYM and nutrients removed by crops under different treatments. The approximate amount of N available for the succeeding crop after meeting its own requirement out of the biologically fixed N in soil by greengram was considered as 37 kg N ha^{-1} (Sharma, Sekhon, and Singh 2004) and this was considered as fertilizer input to the system while calculating the nutrient balance.

Efficiency indices

The economic yield of potato/greengram was converted into sunflower equivalent yield by taking into account the prevailing market price of these crops in the respective years of experimentation.

$$\text{Sunflower economic equivalent yield of potato or greengram}$$
$$= (\text{Yield of potato or green gream x Price of potato or greengram})/\text{Price of sunflower}$$

The price of potato varied from 0.08 to 0.09 USD 4.05 kg^{-1}, greengram from 0.55 to 0.60 kg^{-1} and that of sunflower from 0.49 to 0.54 USD kg^{-1} in different years.

Sunflower equivalent yield of all these crops was summed up to calculate the system productivity in terms of sunflower economic equivalent yield (SFEY). The production efficiency (PE) was worked out by dividing the total production of the sequence by the total duration of the crops grown in rotation. The PE in economic terms was calculated by taking the net return instead of the total production of the system. The costs and returns were calculated on a yearly basis and then averaged.

The agronomic efficiency (AE) of the system was calculated as an increase in the total production for the system as a whole per unit of total fertilizer applied in the sequence (Delogu et al. 1998).

$$\text{AE (kg yield per kg fertilizer applied)} = (Y_f - Y_0)/F_{appln}$$

where Y_f is the sunflower economic equivalent yield at a certain level of applied fertilizer and Y_0 is the sunflower equivalent yield measured in the unfertilized plot (control).

Sustainability yield index

Minimum guaranteed yield that could be obtained relative to the maximum observed yield over the years for the potato-sunflower-greengram cropping system was quantified through the sustainability yield index (SYI). The SYI, denoted as 'η' of a treatment 't' over a period of 'n' years, was derived to identify the sustainable nutrient management practice for the system as a whole as per Vittal et al. (2003).

$$\eta_t = (Y_t - \sigma)/Y_{\max}$$

whereY = estimated mean yield of t;σ = estimate of standard error; Y_{max} = observed maximum yield.

The nearness of SYI to 1.0 implies the closeness to an ideal situation that can sustain maximum crop yields over years, while deviation from 1.0 indicates the losses to sustainability.

Statistical analysis

Individual parameters were subjected to one-way analysis of variance (ANOVA) technique as per the randomized block design to determine the treatment effects using statistical program OPSTAT (www.hau.ernet.in/opstat.html). Mean comparison was performed based on Duncan's Multiple Range Test (DMRT) at the 0.05 probability level.

Results and discussion

Crop productivity

Under continuous cropping of potato-sunflower-greengram raised with different combinations of nutrients applied to potato/sunflower and their residual soil fertility to greengram, significant ($p < 0.05$) differences in yield were observed over the years (Table 2). Weather variation might have caused these yearly variations in yield. Overall, potato yield was the highest in 2006–2007, the first year, and relatively lower yields were obtained in the subsequent years. Sunflower yield was significantly higher during 2007–2008 and 2008–2009 while greengram yielded the maximum during 2009–2010. The crops grown in rotation responded to the application of additional nutrients compared with the control over the study period (Figure 1). The cumulative response of nutrients on the yield of either of the crops was observed with the passage of time, being the lowest at the initiation (2006–2007) and the highest at the end (2009–2010) of the study period. The pooled data presented in Table 3 indicated that all the nutrient management practices resulted in significantly higher yield with 55.6–133.6, 29.3–79.3 and 11.2–34.3% yield superiority

Table 2. Probability level of significance for yield and yield components of crops in potato-sunflower-greengram cropping sequence.

Potato	2006–07	2007–08	2008–09	2009–10
Tuber yield (t ha^{-1})	0.00001	0.00000	0.00001	0.00000
Sunflower[#]				
Seed yield (t ha^{-1})	0.00001	0.00041	0.00001	0.00038
Plant height (cm)	–	0.13405	0.00048	0.00000
Stem girth (cm)	–	0.00001	0.00004	0.00000
Head diameter (cm)	–	0.00010	0.00102	0.00007
100-seed weight (g)	–	0.00214	0.00209	0.00204
Oil content (%)	–	0.33495	0.02832	0.01091
Oil yield (t ha^{-1})	–	0.00051	0.00000	0.00024
Greengram[‡]				
Seed yield (t ha^{-1})	0.00158	0.01105	–	0.00018

[#]Data not available during 2006–2007; [‡]Greengram crop failed during 2008–2009 due to intense rains immediately after germination followed by continuous water-logging. Probability values <0.01 and <0.05 signify that the treatment means are significantly different at 1 and 5% level, respectively.

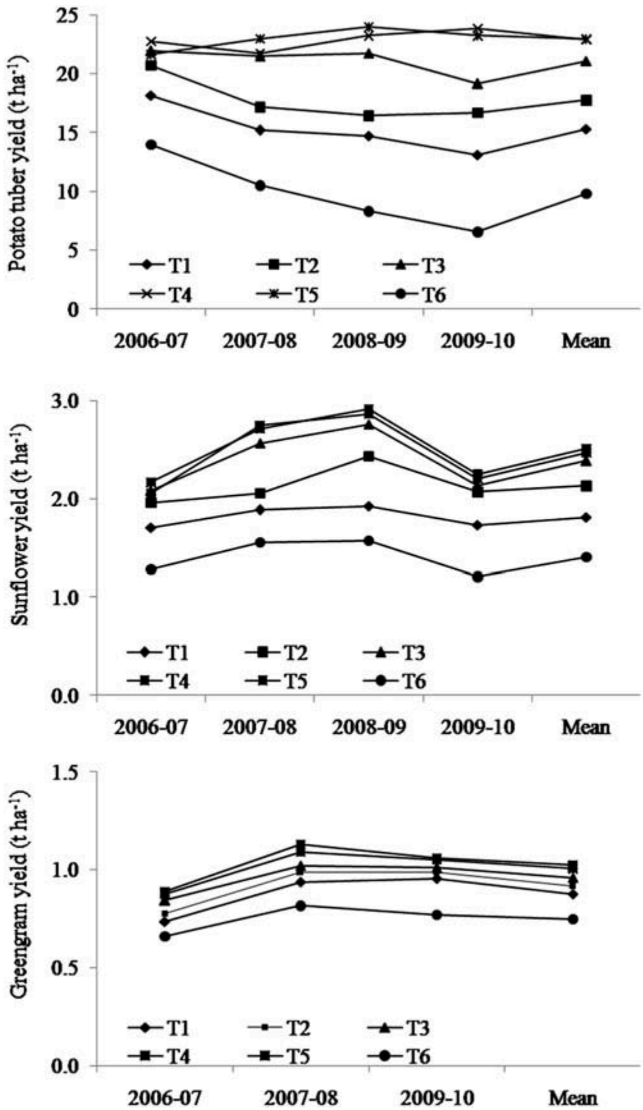

Figure 1. Effect of nutrient management practices on yield of potato, sunflower and greengram over four crop cycle.
Fertilizer application in potato-sunflower-greengram cropping sequence; T_1: N-N-0; T_2: NP-NP-0; T_3: NPK-NPK-0; T_4: 150% NPK-150% NPK-0; T_5: NPK + FYM -NPK-0; T6: Unfertilized control (0–0–0).

in potato, sunflower and greengram, respectively, over that without application of any nutrient, i.e. absolute control (T_6).

In potato, soil incorporation of FYM (5 t ha^{-1}) supplemented with the recommended NPK resulted in the highest tuber yield (22.94 t ha^{-1}), which was significantly superior to the rest of the treatments, except for the 150% NPK application (Table 3). This could be ascribed to the improved nutrient availability through the mineralization of organic manures leading to increased size and number of tubers. Previous studies also highlighted the beneficial response of FYM as a supplement to inorganic fertilization in improving the tuber yield of potato (Ngullie et al. 2011; Singh and Lal 2011). Apparent yield decline was observed in K (T_2) and PK (T_1) omission plots, indicating that the inherent soil phosphorus (P) and potassium (K) were not sufficient enough to meet the crop requirements (Table 3). K omission reduced potato yield by 15.8%, while skipping

Table 3. Mean yield and yield components of crops in sunflower-based cropping system as influenced by nutrient management practices.

Nutrient management practices		Potato tuber yield (t ha^{-1})	Sunflower							Greengram seed yield (t ha^{-1})
			Seed yield (t ha^{-1})	Plant height (cm)	Stem diameter (cm)	Head diameter (cm)	100-seed weight (g)	Oil content (%)	Oil yield (t ha^{-1})	
N-N-0	T_1	15.28^{d}	1.81^{d}	140.1^{c}	6.47^{d}	14.24^{c}	5.33^{c}	36.1^{b}	665^{c}	0.88^{d}
NP-NP-0	T_2	17.73^{c}	2.13^{c}	151.9^{b}	7.14^{c}	15.76^{b}	5.69^{b}	36.9^{a}	808^{b}	0.92^{cd}
NPK-NPK-0	T_3	21.06^{b}	2.38^{b}	155.8^{ab}	7.57^{b}	17.03^{a}	6.03^{a}	37.5^{a}	931^{a}	0.96^{bc}
150% NPK-150% NPK-0	T_4	22.88^{a}	2.51^{a}	157.9^{a}	8.17^{a}	17.78^{a}	6.15^{a}	37.5^{a}	983^{a}	1.03^{a}
NPK + FYM -NPK-0	T_5	22.94^{a}	2.47^{ab}	155.9^{ab}	7.90^{a}	17.07^{a}	6.04^{a}	37.1^{a}	964^{a}	1.01^{ab}
Unfertilized control (0–0–0)	T_6	9.82^{e}	1.40^{e}	130.9^{d}	5.83^{c}	13.31^{d}	5.07^{d}	35.7^{c}	514^{d}	0.75^{e}

FYM: Farmyard manure @ 5 t/ha; Sunflower yield components indicate 3-year mean data; Data followed by the same small case letters within columns do not differ significantly according to Duncan's Multiple Range Test (p < 0.05).

both P and K resulted in 27.4% lower tuber yield compared to that obtained with the recommended NPK (21.06 t ha^{-1}). Increasing the fertilizer dose by 50%, i.e. 150% NPK, enhanced potato tuber yield by 8.6% while additional incorporation of FYM further improved the yield by 8.9% over the recommended dose of NPK.

The highest yield of sunflower (2.51 t ha^{-1}) obtained with the application of 150% NPK was statistically at par with the treatment receiving FYM @ 5 t ha^{-1} + 100% NPK to potato followed by 100% NPK to sunflower (Table 3). Increasing availability of N, P and K resulted in significant improvement in growth (head diameter, stem girth) and yield indices (100-seed weight) and thus contributed in achieving higher yield. These findings are in accordance with those reported earlier by Wang et al. (2008), Suryavanshi, Sudhakara Babu, and Suryawanshi (2015) and Sheoran et al. (2016a). The crop fertilized with the recommended NPK (T_3) provided 31.5 and 11.7% yield gains over sole N and NP applied together, respectively, indicating the role of balanced fertilization in improving sunflower yields. The FYM applied to potato increased the sunflower yield by 0.09 t ha^{-1} over the recommended dose of nutrients (T_3).

Productivity of greengram, which was raised in sequence with potato-sunflower, on residual soil fertility was significantly influenced ($p < 0.05$) by the different nutrient management practices applied to preceding crops in rotation (Table 3). Additional application through FYM (5 t ha^{-1}) or 150% recommended dose of fertilizer (RDF) accompanied 5.2–7.3% yield over the application of RDF alone (T_3). Nitrogen application alone to preceding crops increased greengram yield by 17.3%, while adding NP both to the cropping sequence further enhanced yield by 22.7% over the control (0.75 t ha^{-1}).

System productivity

The system productivity calculated on a pooled yield basis expressed in terms of SFEY revealed significant response in yield with the application of additional nutrients over the recommended dose of nutrients (Table 4). The productivity of potato-sunflower-greengram increased by nearly twofold with the best nutrient management practice (150% NPK to both potato and sunflower) compared with the control. The highest SFEY of 7.21 t ha^{-1} obtained with 150% NPK application was significantly higher (7.0%) than the recommended fertilizer application (T_3). Application of FYM in addition to the recommended dose of nutrients to potato also resulted in 6.2% higher SFEY than the application of RDF alone (6.74 t ha^{-1}), but was at par with 150% NPK. Nutrient inadequacy or imbalanced fertilization in the cropping sequence than the recommended dose resulted in significantly lower yields. Skipping PK nutrition (T_1) resulted in 23.8% decline in system productivity while K omission (T_2) alone accounted for 12.6% reduction in yield when compared to the recommended dose of nutrients (T_3).

Table 4. Mean system productivity, sustainability and resource-use efficiency of sunflower-based cropping system as influenced by nutrient management practices.

Nutrient management practices		System productivity (t SFEY ha^{-1})	Sustainability Yield Index (SYI)	Production Efficiency (kg SFEY $ha^{-1}day^{-1}$)	Production Efficiency (USD $ha^{-1}day^{-1}$)	Agronomic Efficiency (kg kg^{-1})
N-N-0	T_1	5.14^d	0.62^d	19.85^d	5.19^d	4.95^d
NP-NP-0	T_2	5.89^c	0.66^c	22.74^c	6.65^c	6.66^{ab}
NPK-NPK-0	T_3	6.74^b	0.71^b	26.20^b	8.89^b	7.03^a
150% NPK-150% NPK-0	T_4	7.21^a	0.75^a	27.98^a	9.72^a	5.96^c
NPK + FYM -NPK-0	T_5	7.16^a	0.76^a	27.85^a	9.98^a	6.94^{ab}
Unfertilized control (0-0-0)	T_6	3.73^e	0.48^e	14.34^e	2.49^e	-

FYM: Farmyard manure @ 5 t/ha; SFEY: sunflower economic equivalent yield; Data followed by the same small case letters within columns do not differ significantly according to Duncan's Multiple Range Test ($p < 0.05$).

Significantly higher system productivity with the application of 150% RDF (7.21 t ha^{-1}) or with FYM (5 t ha^{-1}) to potato along with RDF to both potato and sunflower (7.16 t ha^{-1}) over the recommended dose of nutrients (6.74 t ha^{-1}) reveals that these crops are highly responsive to additional nutrition and require more nutrients than presently recommended for these crops. However, the residual effect of nutrients applied to the previous crops relative to the mean productivity of greengram was meager as the increase in its yield under the best nutrient combination (T_4) was only 0.28 t ha^{-1} over the control (Table 3). This suggests that greengram is a self-sustaining crop and responds little to residual soil fertility as far as the seed yield is concerned. Rather, inclusion of greengram (legume) in the cropping system is beneficial owing to its known contribution in nitrogen addition through biological nitrogen fixation, addition of a large quantity of leaf litter and root biomass, enhanced microbial activity and enzyme synthesis, and thus accumulation with increased C turnover in the cropping sequence (Ghosh et al. 2007; Lupwayi and Kennedy 2007). Thus, improved nutrient availability and subsequent better uptake might have resulted in the greater dry-matter production and improved yield attributes culminating in improved system productivity.

Sustainable yield index

Reduced or imbalanced fertilization to crops grown in sequence (potato-sunflower) resulted in lower values of SYI (0.62 for T_1 and 0.66 for T_2) than the RDF (0.71). The SYI further improved with increased nutrition or FYM application to crops grown in rotation. The highest SYI was recorded in treatment involving the combined use of the recommended NPK with FYM (0.76), followed by 150% NPK (0.75). The higher value of SYI in the FYM-treated plot also suggests that the productivity of sunflower-based cropping system can not only be improved but also sustained with balanced fertilization and the integration of inorganic fertilizers with available organic manure (Suryavanshi, Sudhakara Babu, and Suryawanshi 2015). The lowest SYI (0.48) was recorded in the non-manured plot.

Production efficiency

The PE, i.e. per day production of the cropping sequence, mirrored the yield responses (Table 4). Irrespective of the nutrient management practices, improvement in PE with the different treatments applied to crops grown in rotation was noticed in comparison to the un-manured control. The mean PE of the system calculated over the 4-year cropping sequence (potato-sunflower-greengram) varied from 19.85 kg ha^{-1} day^{-1} (T_1) to 27.98 kg ha^{-1} day^{-1} (T_4) compared to 14.34 kg ha^{-1} day^{-1} under absolute control (T_1). The PE in terms of monetary returns was the most remunerative (9.98 USD ha^{-1} day^{-1}) with the application of 100% NPK + FYM @ 5 t ha^{-1} to potato and 100% NPK to sunflower, followed by 150% NPK application to both crops (9.72 USD ha^{-1} day^{-1}). The declining trend of PE was observed with nutrient inadequacy or imbalanced fertilization.

Agronomic efficiency

The efficiency of the applied nutrients evaluated as AE was the highest (7.49 kg kg^{-1}) with the recommended fertilization, followed by the FYM-treated plot (Table 4). Each additional unit of P and K nutrition improved system productivity (SFEY) by 18.9 and 11.0 kg kg^{-1} of applied fertilizer, respectively. Relative response (system productivity basis) in yield to increased fertilization followed the diminishing rate of return with 5.96 kg kg^{-1} with 150% NPK fertilization (T_4).

Nutrient uptake and apparent balance

The total nutrient uptake in the system perspective was maximum for N, followed by K and P (Table 5). The lowest nutrient uptake and the highest negative balance were recorded with the unfertilized control, followed by treatments involving nutrient inadequacy or imbalanced

Table 5. Mean effect of nutrient management practices on nutrient uptake and apparent balance.

Nutrient management practices		Total input[a] (kg ha^{-1})			Total output[b] (kg ha^{-1})			Apparent balance (kg ha^{-1})		
		N	P	K	N	P	K	N	P	K
N-N-0	T_1	284.5	0.0	0.0	313.2	24.7	221.1	−28.7	−24.7	−221.1
NP-NP-0	T_2	284.5	40.4	0.0	326.4	56.1	270.4	−41.9	−15.7	−270.4
NPK-NPK-0	T_3	284.5	40.4	77.1	316.9	56.4	310.2	−32.4	−16.0	−233.1
150% NPK-150% NPK-0	T_4	408.3	60.6	115.6	392.8	58.9	336.3	15.5	1.7	−220.7
NPK + FYM -NPK-0	T_5	327.5	50.4	123.6	323.3	56.8	322.3	4.2	−6.4	−198.7
Unfertilized control (0-0-0)	T_6	37.0	0.0	0.0	148.4	26.6	154.7	−111.4	−26.6	−154.7

[a]Total inputs included NPK added through fertilizers + FYM + estimated N added through biological N_2 in soil by greengram as per the treatments.
[b]Total outputs included total NPK uptake by potato + sunflower + greengram.

fertilization, indicating mining of nutrients from native soil reserves in the absence or suboptimal application of the applied nutrients. The current inorganic fertilization recommendations (187.5:27:52 kg ha^{-1} of NPK for potato and 60:13:25 kg ha^{-1} of NPK for sunflower) also showed a negative balance (−32.4 kg ha^{-1} for N, −16.0 kg ha^{-1} for P and −233.1 kg ha^{-1} for K), which indicates that the nutrient application based on the current existing blanket recommendations are not adequate enough for achieving optimum yields and may not be able to sustain the productivity of the potato-sunflower-greengram cropping system. The net negative soil nutrient stock for K with all the treatments indicates the high requirement of this nutrient by the crops. The apparent N and P balance in the soil was positive with only 150% NPK application to each of potato and sunflower crops, which corroborates the need for higher doses of nutrients to maintain/sustain the productivity of the potato-sunflower-greengram cropping system.

Residual soil fertility

The greatest negative balance of $KMnO_4$-N, Olsen's P and NH_4OAc-K contents of soil and the maximum depletion in soil organic carbon (OC) was observed where fertilizer/manure was not applied at all throughout the cropping sequence, followed by treatments involving inadequate/imbalance fertilization (Table 6). Application of P in conjunction with N improved the available N status of the soil as compared to N applied alone. Continuous application of N and NP only had a depressive effect on the available K content in the soil. Greengram grown in rotation contributed a small amount of OC and biologically fixed N_2 to the succeeding crops.

Incorporation of FYM along with 100% RDF to potato in the cropping sequence resulted in improved residual soil properties with maximum buildup of soil OC along with positive gains in primary nutrients (NPK) followed by the treatment comprising 150% NPK application. This might be due to the multidimensional role of FYM ranging from building up of organic matter, improving soil aggregation, soil permeability, and related physicochemical properties of the soil (Singh, Ahlawat, and Singh 2013). Increase in available N might be due to the direct addition of N through the FYM to the available pool of the soil. It could also be attributed to the favorable effect of FYM on

Table 6. Residual soil fertility status at the end of experiment in relation to nutrient management practices.

Nutrient management practices		$KMnO_4$-N (mg kg^{-1} soil)	Olsen's P (mg kg^{-1} soil)	NH_4OAc-K (mg kg^{-1} soil)	Organic C (g kg^{-1} soil)	Dehydrogenase activity (µg TPF g^{-1} soil 24 h^{-1})
N-N-0	T_1	44.5 (−11.2)	5.8 (−13.4)	70.8 (−13.3)	1.38 (−8.0)	29.2
NP-NP-0	T_2	45.4 (−9.3)	6.1 (−8.9)	76.5 (−6.0)	1.48 (−1.3)	29.8
NPK-NPK-0	T_3	46.2 (−7.8)	6.3 (−5.9)	77.6 (−5.0)	1.56 (4.0)	30.2
150% NPK-150% NPK-0	T_4	53.5 (6.9)	7.4 (10.4)	84.3 (3.2)	1.60 (6.7)	31.4
NPK + FYM -NPK-0	T_5	52.1 (4.2)	8.0 (19.4)	86.4 (5.8)	1.71 (14.0)	41.6
Unfertilized control (0-0-0)	T_6	39.5 (−21.1)	5.3 (−21.3)	62.5 (−23.6)	1.31 (−12.7)	27.4
CD (P = 0.05)		2.72	0.40	5.98	0.012	2.45

Figures in parentheses indicate per cent gain (+) or loss (-) over initial soil-test values.

the growth and multiplication of soil microbes, which might have contributed to the conversion of organically bound N to the mineralizable form (Sharma et al. 2011). The increase in available P might be due to the decomposition of organic matter while that of available K might be ascribed to the direct addition of K to the available pool of the soil besides the reduction in K fixing and release of K due to the interaction of organic matter with clay.

Dehydrogenase activity

Treatments receiving 100% RDF to crops resulted in 4.9% higher DHA in soil after 4 years of cropping cycle in comparison to unfertilized control (Table 6). Supplementation of FYM resulted in the highest DHA (41.6 µg TPF g^{-1} soil 24 h^{-1}), further increased DHA by 44.4% over the unfertilized control plot. This can be attributed to more substrate availability with FYM and NPK application treatment owing to enhanced enzymatic activity by organic sources leading to enhanced mineralization with a concomitant increase in CO_2 release and consequently soil aeration (Muhammad, Muller, and Georg Joergensen 2007).

Economics

Returns from the potato-sunflower-greengram system over the four-year crop cycle varied not only due to the variable effect of treatments on crop performance but also due to the fluctuating cost of the inputs and price of produce (Figure 2). The monetary returns relative to nutrient addition substantiated the superiority of any combined fertilizer/manure application at the rates examined compared to unfertilized control. Economic analysis further highlighted favorable long-term turnover with the FYM-treated plot in the cropping sequence compensating additional costs incurred. Soil incorporation of FYM in potato supplemented with the recommended NPK fertilization (T_5) recorded higher net returns (USD 2520 ha^{-1}) and boron to carbon (B:C) ratio (2.91) when compared with the recommended nutrition to crops grown in sequence (USD 2232 ha^{-1}). Sole reliance on fertilizer N application or imbalance nutrition (NP only) is not a cost-cutting measure to achieve optimum yields as it resulted in lower returns and B:C ratio compared to the balanced application of nutrients.

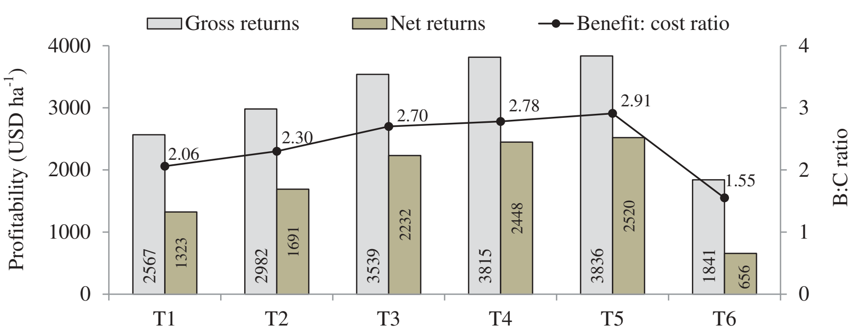

Figure 2. Mean monetary costs and returns over four crop cycles (2006–2007 to 2009–2010) as influenced by nutrient management practices in sunflower-based cropping system.

Fertilizer application in potato-sunflower-greengram cropping sequence; T_1: N-N-0; T_2: NP-NP-0; T_3: NPK-NPK-0; T_4: 150% NPK-150% NPK-0; T_5: NPK + FYM -NPK-0; T6: Unfertilized control (0–0–0).

Conclusions

This study provides precise information on the sustainability and productivity of sunflower-based cropping sequences under resource constraints and nutrient budgeting while considering the utilization of residual and cumulative soil nutrient balance along with added fertilizers to the crops grown in rotation. Apparent yield decline was observed in the total productivity of the system where K and PK nutrition was skipped. In contrast, improvement in SFEY by 18.9 and 11.0 kg kg^{-1} was noticed with each additional unit of P and K applied, respectively. Potato-sunflower-greengram cropping sequence needs to be supplemented with FYM application along with the recommended NPK (potato/sunflower) along with the inclusion of legumes for improving the overall productivity, profitability and sustainability of the system. Improvement in soil chemical and biological properties was observed in the FYM-treated plots over the initial values and reasonably good yield of 1 t ha^{-1} was harvested with greengram raised on residual soil fertility. The recommended fertilization maintained net negative soil nutrient stock and residual soil fertility for all the primary nutrients, apparently highlighting the need to rethink and validate the current blanket inorganic fertilizer recommendations in the system perspective. This study generated comprehensive data to find out the best nutrient management practice in sunflower-based cropping sequence, thus providing the necessary input to the researchers and developmental agencies who wish to enhance food and nutritional security in tropical countries like India.

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