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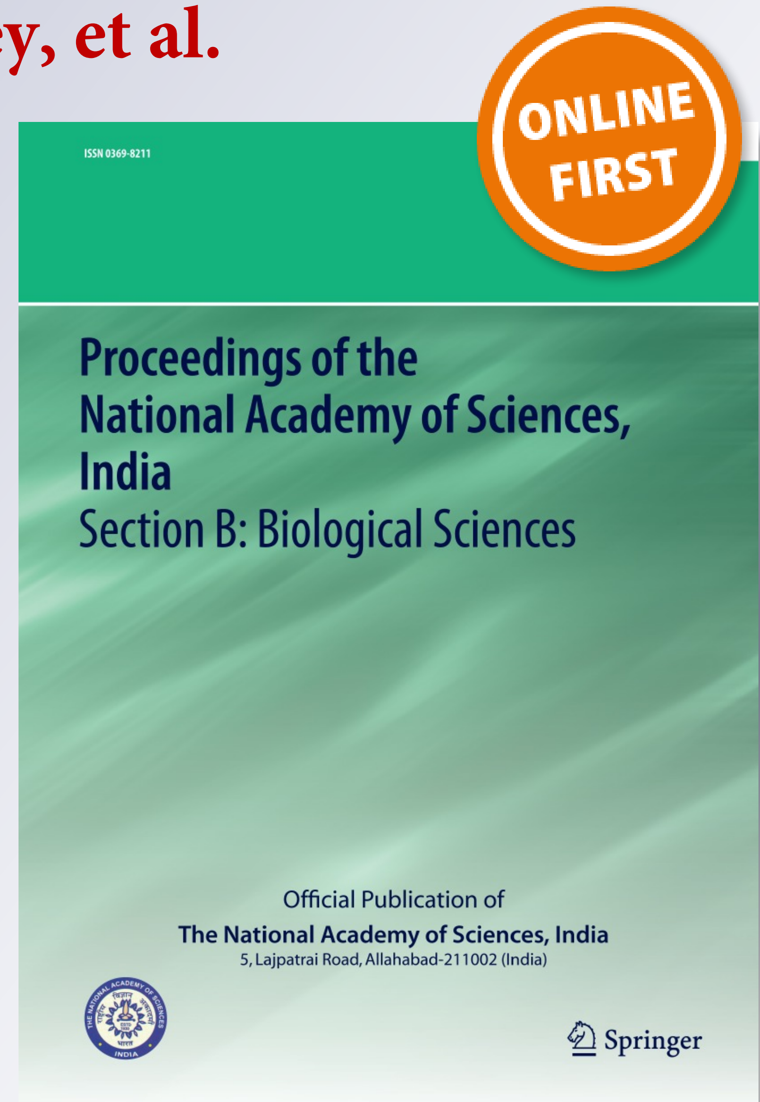

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RESEARCH ARTICLE

Farmer Involvement in the Development and Adoption of Improved Nutrient Management Technologies Using the Mother–Baby Trial Approach in Vertisols

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Abstract Research findings are often not adopted by farmers, for which many reasons have been suggested including poor communication between researchers and farmers. Mother–baby trials, involving on-farm participation to introduce and test technology options, was used to evaluate possible nutrient management technologies in a soybean–wheat system on vertisols deficient in N, P, S and Zn in Madhya Pradesh, India. Seven treatments were tested in four mother trials in 2005–2006 and 2006–2007 on farmers' fields of soybean (monsoon season) and wheat (rabi season) in the Rajgarh and Bhopal districts. In soybean, balanced fertilization (BF) with recommended rates (kg ha^{-1}) of 25 N, 26 P, 17 K, 20 S, and 5 Zn and Integrated Nutrient Management (INM2) (50 % of the recommended inorganic fertilizer + 5 t farmyard manure ha^{-1} + seed inoculation with *Rhizobium*) increased seed yield by ca. 26 % over the farmers' practice (FP). In wheat, BF (120 N, 26 P, 17 K, and 20 S kg ha^{-1}) and INM2 (75 % of the recommended inorganic fertilizer + P-solubilizing bacteria) increased grain yield by ca. 17 % over the FP treatment. Two sets of >90 baby trials conducted by farmers in 2007–2008 and 2009–2010 in 10 villages showed the benefits of these two promising technologies. In poor-yielding fields of soybean (seed yield <1 t ha^{-1}), there was no benefit of applying fertilizers. In contrast, INM2 increased grain yield by 48 % over the FP treatments in fields with fewer limitations. In 2007–2008, wheat responded well to INM2 in fields irrigated three to four times but not in those where irrigation was limited. Field days conducted in 2007–2008 helped the farmers understand the importance of timely control of weeds and insect pests in soybean, and almost all 98 farmers produced higher soybean seed yield over the FP with BF and INM2 during 2009–2010. In this season with timely winter rainfall, almost all farmers at all levels of wheat production obtained good responses to BF and INM2 of 44 and 28 %. The involvement of farmers from the outset proved

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valuable in the adoption of improved nutrient management technologies for higher productivity of the soybean–wheat system, and farmers became aware that higher yields through better nutrient managements are achieved with proper weed and insect pest management in soybean and adequate irrigation in wheat.

Keywords Soybean–wheat · Vertisol · Mother–baby trial · Fertilizer · Farmyard manure · Integrated nutrient management

Introduction

Many agricultural technologies have been developed by researchers worldwide, but these technologies have not been adopted by farmers in many instances. Many reasons, including poor communication of results along with high costs and other socio-economic constraints, have been put forward for poor uptake [1] resulting in a yield gap at local, regional, and global levels [2]. One way that has been shown to improve adoption of technologies is the involvement of farmers throughout the developmental process, from the initial inclusion and testing of treatments through to experimentation by farmers themselves [3]. It is important also that researchers remain involved with the same network of partners [4].

The semi-arid tropical regions of India cover 73 Mha of vertisols and associated soils. In Madhya Pradesh, vertisols are dominant soils which occupied 19.3 Mha out of total geographical area of 44.3 Mha. This soil is derived from basalt of Deccan trap with 30–60 % clay content. The CEC of this soil varies from 30 to 55 cmol (p^+) kg^{-1}. Smectite is its dominant clay mineral. Organic C content of the soil varies from 3 to 7 g kg^{-1}. Deficiencies of N, P, S, and Zn are common due to intensive cropping [5]. Field Surveys conducted in 40 districts of Madhya Pradesh revealed that most probable numbers (MBN) of rhizobia in all districts were mostly below 100 cells g^{-1} in surface soil (range 9–162, mean 72 ± 7 cells g^{-1}) which was found to be much below the threshold for optimum nodulation and reinforced the need to practice regular inoculation. Inoculation of *rhizobial* strains isolated from good nodulation areas increased soybean yield by 22 % over un-inoculated control on farmers' fields [6].

Staff of the Indian Institute of Soil Science (IISS), located near Bhopal (23°18′N; 77°24′E), Madhya Pradesh, India have conducted fertilizer experiments on vertisols over the past 20 years. Soybean (*Glycine max* (L.) Merr. seed yield with the application of fertilizers has been increased from 1.1 t ha^{-1}, the mean yield in India over the past 5 years [7] has been >2.0 t ha^{-1} [8, 9]. These findings have led to recommended rates of N, P, K, S, and Zn on vertisols in Madhya Pradesh. Farmyard manure (FYM) is available to many farmers, and benefits of this source of nutrients have also been shown at IISS [10, 11]. Improved nutrient management practices have been implemented by some farmers, but yields of soybean seed and wheat (*Triticum aestivum* L.) grain in Madhya Pradesh often do not reflect the favorable conditions of the monsoonal climate nor of the many inherently good soils.

Small holder farmers in countries such as India face a soil fertility crisis. Soil surveys in semi-arid regions have consistently shown multi-nutrient (N, P, K, S, and Zn) deficiencies due to continuous cropping with limited use of nutrient inputs [8]. This results in long-term land degradation, but it is likely that the technologies currently available are poor fit with resources available to farmers or do not comply with their investment priorities and attitudes to risk. The involvement of farmers in research activities may help to develop technologies that are better suited to small holder conditions; hence, they may be more readily adopted.

The mother–baby trial (MBT) approach uses on-farm participation to introduce and test a range of technology options suited to a heterogeneous community [12]. The MBT approach involves three levels, described as (i) mother trials, (ii) baby trials, and (iii) farmer experimentation. Mother trials are those which are conducted on a limited number of farmers' fields where a large number of nutrient management interventions exist which may be tested with appropriate replications. Mother trials are designed and managed in collaboration among researchers, advisers, and farmers. Baby trials are not replicated at each site, but are conducted on a large number of farmers' fields with a limited number (usually 2 or 3) of the successful management interventions identified in the mother trials. Baby trials are designed collaboratively by researchers, advisers, and farmers; importantly, the trials are managed by the farmers themselves. This approach serves multiple functions of: (i) generating data on the performance of alternative technologies; (ii) encouraging a dialogue between farmers, advisers, and researchers from the outset, and (iii) encouraging subsequent experimentation by the farmers. The approach can be used to help characterize farmers' risk management strategies, target technology to specific groups, and broaden the adoption of sustainable practices.

From the beginning of this study, it was regarded as important to involve farmers, staff of BAIF Research Foundation (a Non-Government Organization working to improve the socio-economic status of people in rural areas), and agricultural researchers. It is insightful that a farmer in Malawi, where this approach was initiated, first used the term "mother and baby" [12].

Material and Methods

Field experiments conducted at IISS have shown that soybean production is limited by low levels of N, P, S, and Zn, and that overcoming these deficiencies increases seed yield to $\geq$2 t ha^{-1} [10, 13]. These findings have led to recommended inorganic fertilizer rates, known as balanced fertilization (BF). There is a shortage of FYM in Madhya Pradesh, and that which is available is low in nutrients, with ~0.76 % N, 0.22 % P, 0.69 % K, 0.27 % S, and 11 mg Zn kg^{-1} [8, 14]. Where FYM is available, it is recommended that 5 t FYM ha^{-1} be applied to soybean with reduced rates of inorganic fertilizers [15, 16].

An initial project was conducted in 2000–2002, prior to the study reported here, that involved baseline surveys to understand farmers' crop management practices. Despite poor fertility of soil, the majority of farmers in Madhya Pradesh under-fertilized their crops, resulting in annual negative nutrient balances of 0.3 Mt N, 0.06 Mt P, and 0.9 Mt K [8]. It was estimated that about 50 Mt of FYM is produced annually in Madhya Pradesh which could supply 0.4 Mt N, 0.1 Mt P and 0.3 Mt K. Moreover, all of the farmers surveyed believed that FYM improved their soil's physical condition, thereby increasing crop yield. In the case of soybean, farmers felt that the application of recommended rates of all deficient nutrients is risky because the crop is susceptible to pests and diseases and to waterlogging. Farmers are not able to predict the incidence of pests and diseases but this notion can be changed by popularizing pest and weed management strategies along with improved nutrient management practices. In the case of wheat, even farmers who are able to irrigate three to four times post-emergence under-fertilize the crop mainly due to lack of knowledge of the potential yield of varieties with the best management practices.

Mother Trials

Discussions between researchers, social scientists, and farmers in the villages of Geelakhedi, and Mughaliahat, ~30 and 55 km apart from Bhopal in Madhya Pradesh led to the choice of four sites to conduct mother trials during two seasons, 2005–2006 and 2006–2007, on the plots of farmers' fields near these villages. (Severe waterlogging of the soybean seedlings at Site 1 in 2006–2007 resulted in no crop being harvested in this season.) The vertisols at the four sites were low in organic C and in available N, P, S and Zn, but high in available K. The average nutrient status in soils was 0.49 % organic C, 175 kg ha^{-1} available N, 9.2 kg ha^{-1} available P, 8 mg kg^{-1} available S, 0.45 mg kg^{-1} available Zn and 375 kg ha^{-1} available K (Table 1). Soybean cv. JS 335 was grown in summer (monsoon or kharif season), and wheat cv. Lok-1 in winter (rabi season).

Surface soil samples (0–15 cm depth) from plots of the mother trials were collected before experimentation. The samples were air-dried at room temperature, ground to pass through a 2 mm sieve and stored for chemical analyses as described by Redding [17]. Mineralizable N was determined by distillation with alkaline $KMnO_4$ solution and subsequent measurement of NH_4–N in solution. Available P (Olsen-P) was determined by extracting soil samples with 0.5 mol L^{-1} $NaHCO_3$ and available K with 1 mol L^{-1} ammonium acetate. Organic C was determined by the Walkley–Black wet oxidation procedure and available Zn with 0.005 mol L^{-1} DTPA-$CaCl_2$ at pH 7.3 and the Zn concentration in the extract determined by atomic absorption spectrophotometry. Available S was extracted using 0.01 M $CaCl_2$ [18] and the S concentration in the extract determined using the turbidimetric method [19].

Seven treatments (T1–T7), each with three replications, were studied in each mother trial (Table 2). The BF treatment (T1) in soybean tested the recommended rates (kg ha^{-1}) of 25 N, 26 P, 17 K, 20 S, and 5 Zn as inorganic fertilizer. The inorganic fertilizers used were urea, diammonium phosphate (DAP), muriate of potash (KCl), gypsum, and zinc sulfate. The INM1 treatment (T2) involved the application of 50 % of the inorganic fertilizer rates in T1 plus 5 t FYM ha^{-1}. The same nutrients rates were used

Table 1 Initial nutrient status of vertisols at four experimental sites at Geelakhedi, Rajgarh district (Sites 1, 2 and 3), and Mughaliahat, Bhopal district (Site 4), in Madhya Pradesh, India in 2005–2006 prior to conducting the first season's Mother trials

Site	Organic C (%)	$KMnO_4$-extractable N (kg ha^{-1})	Olsen P (kg ha^{-1})	NH_4OAc-extractable K (kg ha^{-1})	$CaCl_2$-extractable S (mg kg^{-1})	DTPA-extractable Zn (mg kg^{-1})
1	0.50 ± 0.05[a]	180 ± 13.9	8.9 ± 1.5	350 ± 20.5	6.5 ± 0.8	0.39 ± 0.11
2	0.48 ± 0.05	170 ± 12.2	9.8 ± 1.9	384 ± 30.1	8.1 ± 1.9	0.40 ± 0.12
3	0.46 ± 0.04	160 ± 10.3	8.0 ± 0.8	372 ± 27.2	8.6 ± 20	0.48 ± 0.14
4	0.52 ± 0.06	190 ± 14.1	10.0 ± 2.3	395 ± 35.7	9.1 ± 2.2	0.55 ± 0.17
Critical limits	0.50	250	11.0	125	10.0	0.50

See text for the methods used for soil analyses. The critical limits are those reported by Ghosh et al. [22] $n = 10$ at each site

[a] Standard deviations for each site

in T3 (INM2) as in T2 plus a seed dressing of 750 g *Rhizobium* inoculum per 75 kg seed which is sufficient to plant 1 ha. The FP treatment (T4) involved the application of 12 kg N and 13 kg P ha^{-1} plus the nutrients in 2 t FYM ha^{-1}. The recommended rates of K, S, and Zn were applied in T5 (as in T1) plus 50 % of the recommended N rate, 75 % of the recommended P rate plus *Rhizobium* inoculation and phosphate-solubilizing bacteria (PSB) (3 kg culture ha^{-1} applied as a soil treatment). Two organic treatments (T6 and T7) tested the effects of 5 t FYM ha^{-1}, with T6 also including *Rhizobium* inoculation and PSB.

The same treatment designations (T1–T7) were used in the wheat crop that followed on the same plots but with different rates of nutrients (Table 2). The recommended rates in T1 were (kg ha^{-1}) 120 N, 26 P, 17 K, and 20 S of inorganic fertilizer; 75 % of these rates in T2; T3 was the same as T2 plus PSB; T4 was the FP treatment (80 kg N ha^{-1} and 23 kg P ha^{-1}); T5 was the same as T3 plus *Azotobacter* (applied in the same manner as PSB); and T6 and T7 used 8 t FYM ha^{-1}, with T6 also including PSB and *Azotobacter*. There was less emphasis on testing the effects of FYM because the wheat crop is planted as soon as possible after harvesting soybean to best utilize residual soil moisture. Furthermore, farmers generally use the FYM available to them during the dry season prior to the arrival of the monsoon (i.e. before planting the soybean crop).

Other crop management practices were those commonly used in the region. Soybean seed was planted in early July at the start of monsoon in 0.3 m rows with ~0.025 m spacing within rows. Weed control was accomplished using a combination of mechanical and chemical (Imazethperan) methods. Stem girdling beetle (*Oberea brevis* S.), the most important insect pest, was controlled by timely spraying with trizophos. The soybean crop was harvested in October. Wheat seed was sown soon after harvesting the soybean crop in rows 0.2 m apart at a rate of 80 kg ha^{-1} after a pre-sowing irrigation of 50 mm. This was followed by irrigation with 50 mm at 25, 50, and 80 days after sowing. Wheat was harvested in March.

All the costs of inputs and outputs in Indian rupees (INR) were those prevailing in the area in 2005–2006, reflecting the information available at the start of this study. The total cost to produce the soybean crop in each treatment was calculated as the sum of all inputs of seed INR 18,750 t^{-1}, weeding INR 2,100 ha^{-1}, insecticide INR 450 L^{-1}, urea INR 5,020 t^{-1}, DAP INR 9,720 t^{-1}, muriate of potash INR 4,640 t^{-1}, gypsum INR 1,850 t^{-1}, $ZnSO_4$ INR 17,000 t^{-1}, FYM INR 200 t^{-1}, ploughing INR 1,500 ha^{-1}, sowing INR 500 ha^{-1}, harvesting and threshing INR 1,200 ha^{-1}, transport and marketing INR 120 ha^{-1}, depreciation on machinery INR 415 ha^{-1}, and interest at 2.5 % per annum on operational costs. In wheat, costs of inorganic fertilizers, FYM, and operations were the same as in soybean and other costs were seed INR 14,250 t^{-1}, irrigation INR 3,335 ha^{-1}, ploughing INR 2,000 ha^{-1}, sowing INR 500 ha^{-1}, harvesting and threshing INR 600 ha^{-1}, transport and marketing INR 240 ha^{-1}, depreciation on machinery INR 415 ha^{-1}, and interest at 2.5 % per annum on operational costs. Gross income in soybean was based on the unit price of INR 11,000 t^{-1}

Table 2 Nutrients applied in seven treatments (T1–T7) in four mother trials conducted on farmers' fields at Geelakhedi in the Rajgarh district and at Mugaliahat in the Bhopal district of Madhya Pradesh, India in 2005–2006 and 2006–2007

Nutrient rates (kg ha^{-1})	T1 BF	T2 INM1	T3 INM2	T4 FP	T5 Modified BF	T6 FYM + *Rhizobium* + PSB	T7 FYM
Soybean							
N	25.0	12.5 (38.0)	12.5 (38.0)	12.0 (15.2)	12.5	(38.0)	(38.0)
P	26.0	13.0 (11.0)	13.0 (11.0)	13.0 (4.4)	19.5	(11.0)	(11.0)
K	17.0	8.5 (34.5)	8.5 (34.5)	0 (13.8)	17.0	(34.5)	(34.5)
S	20.0	10.0 (13.5)	10.0 (13.5)	0 (5.4)	20.0	(13.5)	(13.5)
Zn	5.0	0 (0)	0 (0)	0 (0)	5.0	(0)	(0)
Wheat	**T1 BF**	**T2 INM1**	**T3 INM2**	**T4 FP**	**T5 Modified BF**	**T6 FYM + *Rhizobium* + PSB + *Azotobacter***	**T7 FYM**
N	120.0	90.0	90.0	80.0	90.0	(60.8)	(60.8)
P	26.0	19.5	19.5	23.0	19.5	(17.6)	(17.6)
K	17.0	12.8	12.8	0	12.8	(55.2)	(55.2)
S	20.0	15.0	15.0	0	15.0	(21.6)	(21.6)
Zn	0	0	0	0	0	(0)	(0)

The values are those applied as inorganic fertilizers and in farmyard manure (FYM) (in parenthesis). Full details of the treatments have been supplied in the text

BF balanced fertilization, *INM* integrated nutrient management, *FP* farmers' practice, *PSB* phosphate solubilizing bacteria seed; in wheat, the price of grain was INR 9,750 t^{-1} and that of straw INR 2,000 t^{-1}. Net return in each treatment was calculated as the difference between total income and total cost and the benefit:cost ratio (B:C) by dividing the net return by the total cost.

Grain and straw yields of soybean and wheat were recorded at maturity in the mother trials, followed by the collection of grain and straw samples which were dried in an oven at 70 °C. These samples were ground and stored in an oven at 60 °C until required for analysis. Total N was determined by the semi-Kjeldhal method and the NH_4-N form was measured using the indophenol blue method [20]. Samples were digested in 4:1 nitric: perchloric acid (HNO_3:$HClO_4$) mixture; P was determined by the vanado molybdate method and K by flame photometry [21]. The soil analytical data were evaluated relative to the critical limits determined by Ghosh et al. [22].

Statistical analyses were conducted using standard analysis of variance, and the treatment means compared at the 5 % level of significance using least significant difference (LSD) technique wherever appropriate [23]. In case of mother trials, standard deviations (SD) for each treatment across four sites have also been worked out. In case of baby trials, the lowest and highest yields of soybean and wheat along with mean and SD were computed.

Farmers, advisers, and researchers discussed the results of these mother trials at the end of each season, with special emphasis on their possible suitability for adoption by farmers. It was decided to test two improved nutrient management treatments, T1 (BF) and T3 (INM2), along with the FP treatment (T4) in the baby trials to be conducted by the farmers.

Baby Trials

For many years, agriculturalists have involved farmers in a contractual way to assess new technologies providing valuable information over a wider area than is possible at institutional sites alone. However, these contracts have often left farmers sidelined, and there has been little acceptance of experimental results by the wider community. To overcome this problem, Snapp [12] described the approach in which baby trials in farmers' fields compare a subset of technologies from the mother trials with each baby trial site as a replicate. Decisions on treatments are made collaboratively by all partners, and other management practices recommended. It is up to each farmer, however, to conduct the baby trial in their field.

In 2007–2008, 95 out of 100 baby trials were successfully completed by farmers in 10 villages in the Rajgarh, Vidisha, and Raisen districts of Madhya Pradesh (Table 3) to determine the suitability of the improved nutrient management technologies for adoption by farmers. In these trials, two successful nutrient management interventions identified in the mother trials, BF (100 % of the recommended N, P, K, S, and Zn fertilizer rates to soybean and 100 % of the N, P, K, and S to wheat) and INM2 (50 % of the recommended rates of N, P, K, and S + 5 t FYM ha^{-1} + *Rhizobium* to soybean and 75 % N, P, K, and S + PSB to wheat) were compared to the FP treatment. Soils were analyzed prior to the application of nutrients using the same procedures as for the mother trials. The results indicated that the initial soil fertility status of the 95 successful sites in 2007–2008 showed that 47 % of soils were low in organic C, all soils were low in available N, with 48 % of soils low in available P, and 41 % low in available S, and 52 % low in available Zn (Table 4). No soils were considered deficient in K but, overall, 32 % of soils were deficient in N, P, S, and Zn. In 2009–2010, 98 baby trials at new sites were conducted successfully on fields of six villages (Table 3) using the same treatments as in 2007–2008. The initial soil fertility status of the 98 trial sites was similar to that in 2007–2008, showing that 50 % of soils were low in organic C, all soils low in available N, 47 % soils low in available P, 52 % low in available S, and 60 % low in available Zn (Table 4). All soils were considered to be high in available K.

In both seasons, there were marked differences between the lowest and highest available nutrient values, this being clearly evident by the high SD of the mean values (Table 4). The variability in available nutrients reflects the heterogeneity of the landscape. This may reflect that of the farming community also, with some farmers applying

Table 3 The locations of 95 successfully completed baby trials in 2007–2008 and 98 baby trials in 2009–2010 in the Vidisha, Raisen, and Rajgarh districts of Madhya Pradesh, India

Season	District	Village	Number of baby trials
2007–2008	Vidisha	Rangai	20
		Berkheda	5
		Karayya	12
		Gagandhaba	6
	Raisen	Sanchi	7
		Kamapar	9
		Naunakheda	10
	Rajgarh	Geelakhedi	16
		Sanwas	4
		Turkipura	6
2009–2010	Vidisha	Rangai	7
		Shair	21
		Powanala	29
	Raisen	Dakhna	19
	Rajgarh	Sunari	11
		Geelakhedi	11

higher rates of inorganic fertilizers and FYM over previous seasons while other farmers were not been able to do so.

Considerable organizational effort was taken by researchers and advisers to obtain all agricultural inputs (e.g. seeds, fertilizers) to ensure timely planting of the soybean and wheat crops. Detailed discussions were held among farmers, advisers, and researchers. The weed and insect pest management practices recommended were similar to those used in the mother trials.

Results and Discussion

Mother Trials

At all the four sites in both seasons, the improved nutrient management treatments of BF, INM1, and INM2 (T1, T2, and T3) consistently and significantly increased soybean seed yield over that of the FP treatment (Fig. 1a, b). In all instances, the replacement of some inorganic fertilizer with FYM (T2) was slightly better than the BF treatment, and the added inclusion of *Rhizobium* inoculation (T3) provided a further benefit. Besides the increase in seed yield, T3 saved inorganic nutrient inputs of (kg ha^{-1}) of 12 N, 13 P, 8 K, 10 S, and 5 Zn per crop. The 2005–2006 season was slightly better than 2006–2007 for soybean production, but the BF, INM1 and INM2 treatments increased soybean seed yield on average by ca. 20 % (0.34 t ha^{-1}) in both seasons (Table 5). It is noteworthy that soybean seed yield in the T5, T6, and T7 treatments, in which N and P inorganic fertilizers were reduced or replaced completely by 5 t FYM ha^{-1}, was no better than that of the FP treatment (Fig. 1; Table 5). The mean harvest index (HI) of soybean was 0.35 ± 0.02.

Treatment effects on the contents of N, P, and K in the soybean seed followed that of yield, with considerably more nutrients in seed from the improved nutrient management treatments (BF, INM1, and INM2) than T4–T7 (Table 5). The three improved nutrient management treatments removed an extra (kg ha^{-1}) 38 N, 4 P, and 8 K than the FP treatment in 2005–2006 (Table 5); by comparison, an extra 12 N, 13 P, and 8 K had been applied to the soil (Table 2). Similar results were evident in 2006–2007, but comparisons are more difficult because nutrients were applied to the same plots.

In the 2005–2006 rabi season, the BF and both INM treatments produced significantly higher wheat grain yield of 16–21 % over the FP treatment. As with the soybean crops, consistent and significant results were evident at all four sites and in both seasons, but BF was slightly better than INM1 and INM2 (Fig. 1c, d). The BF yields were on average 22 % higher than that of the FP treatment; increase in the INM treatments averaged 17 %. Improved nutrient management had similar benefits on wheat straw yield at all sites. The mean HI was 0.47 ± 0.02. These findings mirrored results obtained in field experiments conducted at IISS [24].

As expected, the total contents of N, P, and K in wheat grain was similar to the treatment effects on yield (Table 5). For the additional inorganic fertilizer inputs in the BF, INM1, and INM2 treatments over that in the FP treatment of wheat grain yield removed an additional (kg ha^{-1}) 26 N, 14 P, and 24 K in 2005–2006. (These fertilizer inputs applied to the preceding soybean crop were not taken into account.)

The financial implications of the various treatments received special attention when assessing the results of the mother trials. Discussions were held among all collaborators on the sources of information to be used for seed and

Table 4 The initial fertility status of baby trial sites in the Vidisha, Raisen, and Rajgarh districts of Madhya Pradesh, India

Season	Organic C (%)	$KMnO_4$-extractable N (kg ha^{-1})	Olsen-P (kg ha^{-1})	NH_4OAc-extractable K (kg ha^{-1})	$CaCl_2$-extractable S (mg kg^{-1})	DTPA-extractable Zn (mg kg^{-1})
2007–2008						
Lowest	0.33	100	5.6	461	3.8	0.3
Highest	0.90	240	56.6	1283	27.8	1.68
Mean (±SD)	0.54 (±0.14)	137 (±38)	16.8 (±9.8)	765 (±186)	13.5 (±6.0)	0.55 (±0.24)
Samples deficient (%)	47	100	48	0	41	52
2009–2010						
Lowest	0.28	100	1.2	430	5.5	0.3
Highest	0.8	241	25.7	123	24.4	1.4
Mean (±SD)	0.53 (±0.13)	150 (±37)	7.7 (±4.4)	704 (±188)	11.6 (±4.9)	0.55 (±0.24)
Samples deficient (%)	50	100	47	0	52	60

See text for the methods used for soil analyses. The percentage of soil samples considered deficient is based on the critical limits reported by Ghosh et al. [22]

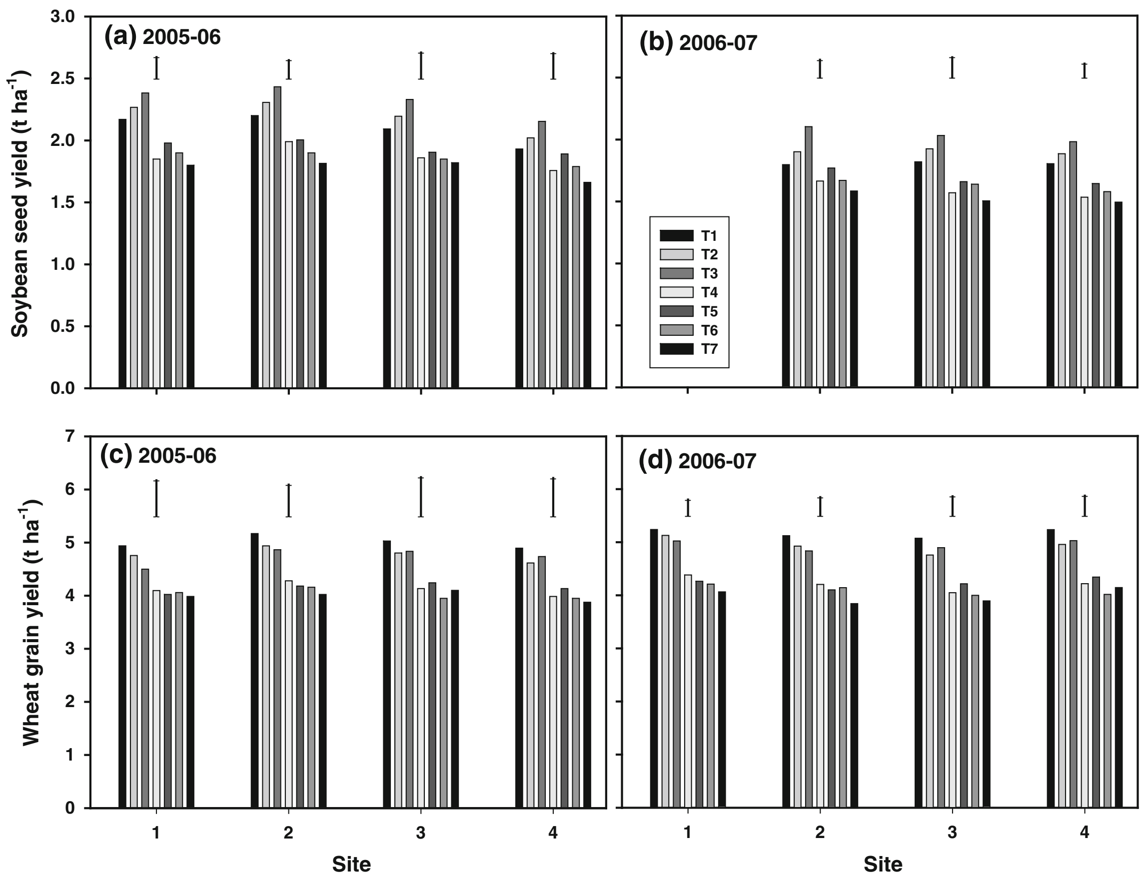

Fig. 1 Effects of seven nutrient management treatments (T1–T7) on soybean seed yield (**a**, **b**) and wheat grain yield (**c**, **d**) in mother trials at four sites in 2005–2006 (**a**, **c**) and 2006–2007 (**b**, **d**) in farmers' fields at Geelakhedi, Rajgarh district, and Mughaliahat, Bhopal district, in Madhya Pradesh, India. Treatment details have been fully described in the text. I = LSD ($P = 0.05$)

grain prices and the costs of inputs, including those of farming operations. The earlier survey [8] revealed that the FYM annually available to farmers with medium-scale (2–4 ha) and large-scale (>4 ha) areas of land can cover only 24–56 % of their land when used at a rate of 5 t ha^{-1}. These farmers would have the option of using either INM1 or INM2 treatments on these areas, with inorganic fertilizers (BF) used on the remaining portion. In contrast with the better-off farmers, those with either <1 ha or 1–2 ha of land would best use either the INM1 or INM2 treatments which involve lower investment but high benefit. After extensive discussions, it was decided that the baby trials would compare the effects of two improved nutrient management treatments, BF and INM2, with the FP treatment in the soybean–wheat system.

Baby Trials

In the first season in which baby trials were conducted by the farmers (2007–2008), there was marked variation in the soybean seed yield in each of the three treatments (Table 6). The highest yield in each treatment was >4-times higher than the lowest, a finding emphasized by the high SD as compared to the mean. The variation in soybean seed yield was lower in 2009–2010, ranging less than twofold. Despite the large variation in yield in each treatment, it was evident that the two improved nutrient management treatments in 2007–2008 had higher mean soybean seed yield of 0.38 t ha^{-1} with BF and 0.78 t ha^{-1} with INM2 (23 and 46 % seed yield increase) than the FP treatment. The benefits were similar in 2009–2010.

While the soybean data presented in Table 6 provide a useful overall summary, sorting the data from the 95 individual fields revealed the situations in which different yield benefits were evident (Fig. 2a). There was little benefit of better nutrient management practices in fields with low yield potential. With soybean seed yield <1 t ha^{-1} in the FP treatment (12 % of farmers), yield was increased by only 0.24 and 0.41 t ha^{-1} in the BF and INM2 treatments. It appeared that low yield resulted from poorer land (e.g. shallow soil) and to higher weed and insect pest infestations. A soybean seed yield of 1 to <2 t ha^{-1} was achieved in the FP treatment in better fields and where farmers were able to implement good management

Table 5 Mean effects of seven nutrient management treatments (T1–T7) on soybean seed yield and N, P, and K contents and on wheat grain yield and N, P, and K contents in mother trials in 2005–2006 and 2006–2007 conducted on four sites in farmers' fields at Geelakhedi, Rajgarh district, and Mughaliahat, Bhopal district, in Madhya Pradesh, India

Season	Treatment	Soybean				Wheat			
		Seed yield (t ha^{-1})	N content (kg ha^{-1})	P content (kg ha^{-1})	K content (kg ha^{-1})	Grain yield (t ha^{-1})	N content (kg ha^{-1})	P content (kg ha^{-1})	K content (kg ha^{-1})
2005–2006	T1	2.10 ± 0.104[a]	177.8 ± 8.8	18.4 ± 1.0	96.7 ± .6.6	5.00 ± 0.109	129.7 ± 5.9	19.6 ± 1.1	113.4 ± .3.0
	T2	2.20 ± 0.109	188.7 ± 8.6	19.6 ± 1.2	103.7 ± 6.2	4.78 ± 0.111	119.6 ± 5.5	17.6 ± 1.2	107.7 ± 4.2
	T3	2.33 ± 0.105	198.8 ± 6.9	21.2 ± 1.0	114.5 ± 7.0	4.79 ± 0.078	120.9 ± 4.6	17.8 ± 0.7	103.7 ± 4.1
	T4	1.86 ± 0.082	151.2 ± 7.3	15.6 ± 0.7	80.3 ± 4.4	4.12 ± 0.105	98.5 ± 5.1	13.8 ± 0.6	83.7 ± 2.6
	T5	1.95 ± 0.048	162.3 ± 4.2	16.8 ± 0.4	87.0 ± 3.4	4.14 ± 0.072	99.8 ± 3.9	14.0 ± 0.8	83.6 ± 2.7
	T6	1.86 ± 0.023	151.8 ± 4.3	15.7 ± 0.5	79.3 ± 4.0	4.03 ± 0.078	93.3 ± 4.2	12.8 ± 0.8	79.3 ± 2.2
	T7	1.77 ± 0.065	141.0 ± 5.9	14.6 ± 0.6	72.5 ± 4.2	3.95 ± 0.085	90.1 ± 5.0	12.3 ± 0.4	76.7 ± 2.8
	LSD ($P = 0.05$)	0.18	16.6	1.9	13.0	0.34	16.5	5.6	29.8
2006–2007	T1	1.81 ± 0.009	162.1 ± 8.0	15.2 ± 0.1	73.3 ± 0.4	5.17 ± 0.071	134.0 ± 3.2	20.1 ± 1.2	117.2 ± 1.9
	T2	1.90 ± 0.016	172.7 ± 2.5	16.4 ± 0.2	79.8 ± 0.9	4.94 ± 0.131	122.9 ± 2.8	17.6 ± 0.4	106.4 ± 2.4
	T3	2.04 ± 0.049	184.3 ± 3.7	17.8 ± 0.5	88.5 ± 2.0	4.95 ± 0.083	123.7 ± 4.0	18.4 ± 1.3	107.0 ± 3.1
	T4	1.59 ± 0.054	136.8 ± 4.9	12.8 ± 0.6	60.3 ± 3.4	4.21 ± 0.117	98.8 ± 4.5	14.1 ± 0.4	85.5 ± 1.2
	T5	1.69 ± 0.055	149.5 ± 4.3	13.9 ± 0.5	66.5 ± 2.9	4.23 ± 0.087	101.0 ± 2.1	14.3 ± 0.5	85.6 ± 0.9
	T6	1.63 ± 0.037	139.4 ± 1.9	13.2 ± 0.3	60.8 ± 1.5	4.09 ± 0.088	94.5 ± 3.6	13.0 ± 0.3	80.6 ± 1.4
	T7	1.53 ± 0.040	127.9 ± 2.5	12.1 ± 0.4	55.0 ± 1.2	3.99 ± 0.123	90.1 ± 3.1	11.9 ± 0.6	76.6 ± 0.8
	LSD ($P = 0.05$)	0.14	12.1	1.35	8.6	0.35	17.6	2.8	21.0

Treatment details have been fully described in the text $n = 12$ at each site

[a] Standard deviations for each treatment across four sites

Table 6 The lowest, highest, and mean soybean seed yield and wheat grain yield in three nutrient management treatments (T1, T3, and T4) in baby trials conducted by farmers in 2007–2008 and 2009–2010 in three districts of Madhya Pradesh, India

Season	Parameter	T1 balanced fertilization		T3 Integrated nutrient management 2		T4 farmers' practice	
		Soybean seed yield (t ha^{-1})	Wheat grain yield (t ha^{-1})	Soybean seed yield (t ha^{-1})	Wheat grain yield (t ha^{-1})	Soybean seed yield (t ha^{-1})	Wheat grain yield (t ha^{-1})
2007–2008 ($n = 95$)	Lowest	0.750	2.00	0.85	2.00	0.63	1.75
	Highest	3.33	6.26	3.63	6.25	2.75	4.38
	Mean (±SD)	2.06 (±0.69)	4.24 (±1.45)	2.46 (±0.80)	4.04 (±1.32)	1.68 (±0.61)	3.27 (±0.81)
2009–2010 ($n = 98$)	Lowest	1.38	3.38	1.50	2.88	0.88	2.50
	Highest	2.13	6.00	2.75	5.38	1.66	4.75
	Mean (±SD)	1.75 (±0.17)	4.68 (±0.58)	2.02 (±0.24)	4.21 (±0.54)	1.33 (±0.16)	3.30 (±0.44)

practices (53 % of farmers). In these situations, increase of 0.38 and 0.78 t ha^{-1} were evident with the BF and INM2 treatments. Improved nutrient management was most evident with the 45 % of farmers with $\geq$2 t ha^{-1} in the FP treatment. With mean soybean seed yield of 2.39 t ha^{-1} in this treatment, the BF and INM2 treatments increased yield by 0.42 and 0.91 t ha^{-1}. In these instances, INM2 was clearly better than BF.

Field days were organized in the study villages to present the results and alert farmers to the importance of controlling weeds and insect pests so as to realize the benefits of improved nutrient management which was benefited by the farmers from participating in the field days, was evident in the second monsoon season. Soybean seed yield ranged from 0.88 to 1.66 t ha^{-1} in the FP treatment, from 1.38 to 2.13 t ha^{-1} with BF, and from 1.50

to 2.75 t ha^{-1} with INM2 (Table 6). Soybean seed yield at low level of production was increased in all treatments despite the season not being as conducive to high production through high rainfall. At the highest levels of production, soybean seed yield increased by >1 t ha^{-1} from the ca. 1.5 t ha^{-1} in the FP treatment (Fig. 2b). This was similar to the finding in 2007–2008. In contrast to this season, however, improved nutrient management increased seed yield even in the lowest-yielding fields. This indicates that the farmers with these fields had paid greater attention to weed and insect pest management, thus reaping the benefit of better nutrient management. Once again, there was increased benefit of including FYM over inorganic fertilizers alone in the provision of nutrients to soybean. Maximum soybean yield with BF and INM2 in 2009–2010 was lower by about one-third than in 2007–2008. This may be due to the poor monsoon of 2007–2008 which allowed better soybean production (through less waterlogging) at the expense of poor wheat yield (through increased moisture stress).

It is noteworthy that the field days were not a one-way transfer of information but a lively discussion of results. Further discussions addressed approaches to some of the shortcomings identified by Misiko et al. [3] to be inherent in participatory monitoring and evaluation. For example, experimental results are often site-specific and cannot be used to predict widespread adoption of a practice. The baby trials conducted in a community may overcome this limitation, a suggestion to be tested in future evaluation of nutrient management practices. Additionally, farmers attributed the higher soybean yield with INM2 to better pod bearing than with BF (ca. 90 and ≤70 plant^{-1}), somewhat in contrast with farmers in western Kenya who concluded that seed yield cannot be predicted on the basis of pod number due to differences in pod filling [3].

As with soybean, there was a large variation in wheat grain yield in the rabi season of 2007–2008 (Table 6) due to differences in nutrient management and in the availability of irrigation. Madhya Pradesh received only 70 % of the normal rainfall during the monsoon of 2007–2008. Indeed, four baby trials with wheat failed because of lack of irrigation water. Out of the 91 successful trials, 45 received 3 or 4 post-planting irrigations, 12 were irrigated twice, and the remaining 34 only once. The wheat which received 3 or 4 post-planting irrigations responded well to BF and INM2 with a mean wheat grain yield of >5 t ha^{-1},

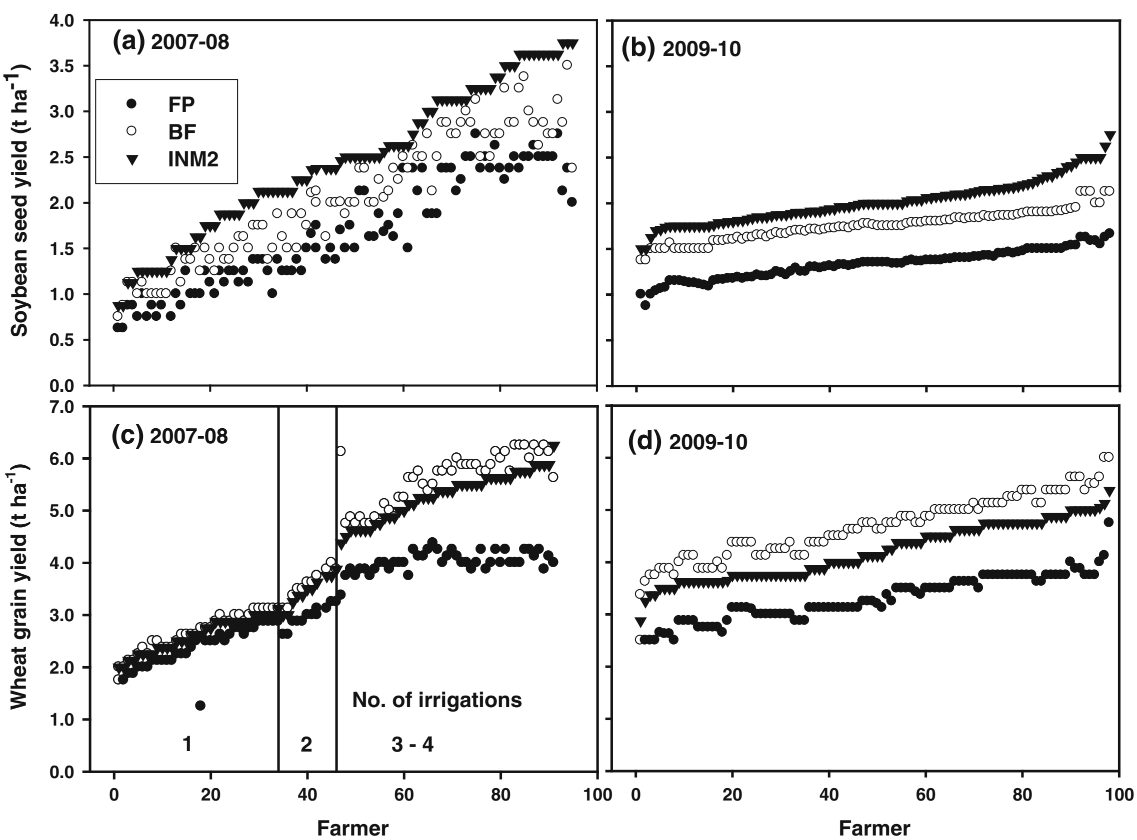

Fig. 2 Soybean seed yield and wheat grain yield in baby trials conducted in 2007–2008 and 2009–2010 in Vidisha, Raisen, and Rajgarh districts in Madhya Pradesh, India testing the effects of the farmers' practice (FP), Balanced Fertilization (BF), and Integrated Nutrient Management (INM2)

twice that in the FP treatment (Fig. 2c). This contrasted to the trials which were irrigated twice (ca. 20 % yield increase) and especially to those with a single irrigation. In this instance, the mean wheat grain yield in the FP treatment was only 2.35 t ha^{-1}, and there was no benefit of improved nutrient management.

The pooled data of 98 successful baby trials in 2009–2010 indicated that the wheat grain yield averaged 3.27 t ha^{-1} in the FP treatment, increasing to 4.24 t ha^{-1} with BF and to 4.04 t ha^{-1} with INM2 (Table 6). The region received three falls of rain at critical times in the rabi season of 2009–2010. The 11 wheat baby trials in Rajgarh district received two post-planting irrigations while the 87 baby trials in Raisen and Vidisha districts were irrigated 3 or 4 times and also received rain. The minimum grain yield in each treatment was higher than in 2007–2008, reflecting the in-season rainfall. Unlike the findings in 2007–2008, there was a good response to improved nutrient management irrespective of yield in the FP treatment (Fig. 2d), a finding also in keeping with decreased moisture stress. However, the maximum grain yield in the BF and INM2 treatments was the same at ca. 6 t ha^{-1}. This indicated the yield potential for wheat grown with current management practices in this region.

Financial Implications

This study was designed to assess the financial aspects of the soybean–wheat system in Madhya Pradesh, India, but it is worthwhile to initially evaluate the two crops separately. Soybean became increasingly important on the vertisols of Madhya Pradesh from 1980 onward. Production of seed exceeding 1×10^6 t for the first time in 1985; current production exceeds 10×10^6 t [7], ca. 75 % in Madhya Pradesh. Gross income, total cost, net return and B:C ratio of soybean averaged over FP, BF, and INM2 treatments in the mother trials were INR 22275, 10386, 11889 and 1.14, respectively. Unlike soybean, wheat has long been an important crop in Madhya Pradesh which produces about 10 % of India's total wheat. Gross income, total cost, net return and B:C ratios of wheat averaged over FP, BF, and INM2 treatments in mother trials are INR 56440, 11189, 45418 and 4.1, respectively. The overall financial advantage of wheat over soybean is clearly evident.

Considered together as a soybean–wheat system over two seasons, the three improved nutrient management treatments in the mother trials gave a 20 % higher gross income than the other four treatments because of their higher yield. The higher gross income required 6 % higher input cost for nutrients. Overall, the improved nutrient management treatments resulted in higher net return as compared to FP treatment (Table 7). The highest net return on investment (INR 61,800 ha^{-1}) was with T3 (INM2) which was 26 % higher than that from the FP treatment. The BF (T1) and INM1 (T2) treatments produced net return only slightly lower than those from the INM2 treatment (24 and 23 % higher than the FP treatment). As with net return, the highest B:C ratio occurred with the INM2 treatment which was considerably better than the FP treatment (Table 7). Whether or not farmers are able to integrate FYM with inorganic fertilizers depends on the quantity of FYM available.

The three nutrient management treatments provided a positive return to farmers based on the mean yield data of the baby trials in the two seasons (Table 8). It was clear that improved nutrient management was financially beneficial but did incur higher costs of ca. INR 1700. Net return was increased by a similar amount with a single post-plant irrigation, but increased >tenfold by the higher wheat grain yield when irrigated three to four times post-planting. The financial reward was also evident by evaluating the B:C which increased in the BF and INM2 treatments especially when wheat was well irrigated.

Table 7 Mean soybean seed yield and wheat grain yield over two seasons (2005–2006 and 2006–2007) in four Mother trials conducted on vertisols at four sites in farmers' fields at Geelakhedi, Rajgarh district, and Mughaliahat, Bhopal district, in Madhya Pradesh, India, and the calculated gross income, total cost, and net return in seven treatments (T1–T7)

Treatment	Soybean seed yield (t ha^{-1})	Wheat grain yield (t ha^{-1})	Gross income (INR ha^{-1})	Total cost (INR ha^{-1})	Net return (INR ha^{-1})	Benefit:cost
T1	1.95	5.09	83,600	22,700	61,000	2.7
T2	2.05	4.86	81,800	21,600	60,300	2.8
T3	2.18	4.87	83,500	21,600	61,800	2.9
T4	1.73	4.17	69,600	20,400	49,200	2.4
T5	1.82	4.19	70,700	21,800	48,900	2.3
T6	1.75	4.06	68,300	20,400	47,900	2.4
T7	1.65	3.96	65,800	20,300	45,600	2.3

Treatment details have been described in the text *T1* balanced fertilization, *T2* integrated nutrient management 1, *T3* integrated nutrient management 2, *T4* the farmers' practice, *T5* modified balanced fertilization, *T6* and *T7* fertilization with farmyard manure

Table 8 Mean soybean seed yield and wheat grain yield in baby trials conducted by farmers on vertisols in 2007–2008 and 2009–2010 in farmers' fields in Vidisha, Raisen, and Rajgarh districts in Madhya Pradesh, India, and the calculated gross income, total cost, net return, and benefit:cost ratio in three nutrient management treatments

Season	Management	Soybean seed yield (t ha^{-1})	Wheat grain yield (t ha^{-1})	Gross income (INR ha^{-1})	Total cost (INR ha^{-1})	Net return (INR ha^{-1})	Benefit:cost
2007–2008	Wheat: 1 post-planting irrigation ($n = 26$)						
	BF	1.81	2.68	52,800	19,600	32,100	1.55
	INM2	2.18	2.62	55,800	20,700	36,200	1.85
	FP	1.37	2.40	44,300	18,400	25,800	1.40
	Wheat: 2 post-planting irrigations ($n = 13$)						
	BF	1.75	3.00	56,100	20,300	34,800	1.63
	INM2	2.03	2.93	58,100	21,300	37,900	1.86
	FP	1.42	2.58	47,100	19,100	28,000	1.46
	Wheat: 3–4 post-planting irrigations ($n = 52$)						
	BF	2.21	5.34	89,800	22,700	67,100	2.96
	INM2	2.65	5.05	90,900	21,600	69,300	3.20
	FP	1.85	3.88	67,600	20,400	47,200	2.31
2009–2010	Wheat: 2 post-planting irrigations ($n = 11$)						
	BF	1.59	3.78	64,000	21,300	42,600	2.00
	INM2	1.76	3.43	61,300	20,300	41,100	2.02
	FP	1.21	2.59	45,000	19,100	25,800	1.35
	Wheat: 3–4 post-planting irrigations ($n = 87$)						
	BF	1.77	4.79	78,300	22,700	55,600	2.45
	INM2	2.05	4.30	75,200	21,600	53,600	2.48
	FP	1.34	3.38	56,000	20,400	35,500	1.74

Treatment details have been described in the text *BF* balanced fertilization, *INM2* integrated nutrient management 2, *FP* farmers' practice

Further Considerations

The valuable information from field experiments on soybean and wheat at IISS over 20 years, the mother trials on farmers fields over two seasons, and the extensive baby trials conducted by farmers also over two seasons may be used further. The simplest way is to update the financial results with the latest data. This would be of particular benefit in situations in which there are relative changes in prices of outputs and costs of inputs. Such information would allow farmers to annually assess the possible financial outcomes of increased nutrient inputs. The financial benefits of improved nutrient management demonstrated in mother and baby trials may be evaluated in more details by calculating the financial returns to farmers who produce high yields and those who do not. It would be especially advantageous to conduct risk assessments for farmers with land of low and high yield potential. The comprehensive data available allow modeling of improved nutrient management technologies over a range in seasonal conditions. Modeling exercises would indicate the probability achieving benefits from applying higher rates of nutrients and the risks involved. Given the range in yields evident in the baby trials, such scenarios may be addressed to farmers who have land with high yield potential and high management skills and those who do not. Finally, the modeling results may challenge researchers to evaluate other technologies which, for example, may improve soybean production in seasons with high monsoon rainfall as evidenced by the abandonment of mother trial Site 1 (Fig. 1b).

Conclusion

Four mother trials provided information on improved nutrient management for soybean and wheat production on vertisols in Madhya Pradesh, India. Both BF and INM2 were better that the FP treatment from production and economic points of view. Discussions among farmers, advisers, and researchers led to the agreement that worthwhile comparisons among these three treatments would be beneficial in baby trials conducted by farmers. The mean response of the 193 baby trials over two seasons showed that BF increased soybean seed yield by 26 % and wheat grain yield by 31 % over the FP treatment. Corresponding values for INM2 were 49 % with soybean and 22 % with wheat. Whether farmers opt to use BF or INM2 depends upon the availability of FYM, a resource that is not sufficient to cover the entire land holding of the medium and large scale farmers every year.

Low soybean yield was achieved by 40 % of farmers in baby trials in 2007–2008 largely due to poor management of weeds and insect pests. The situation was much improved in the second series of baby trials as almost all the farmers implemented timely weed and insect control measures. This was affected by three field days that were conducted during the first year and the observations and measurements by the farmers themselves. Collaboration over an extended period not only demonstrated to farmers the benefits of better nutrient management, but also helped advisers and researchers to understand the limitations under which farmers operate. This allows further modifications to recommended nutrient management practices. The MBT approach clearly demonstrated to farmers the magnitude that BF and INM2 technologies enhance the productivity of the soybean–wheat system in their own fields. Some farmers were exposed to the procedures involved in evaluating treatment effects, and others when the results were discussed among the community. It was, however, the involvement of farmers in the baby trials that was especially instructive. Farmers acknowledged the clear evidence of greater benefits of improved nutrient management in soybean grown on good soils and with proper weed and insect pest management. The importance of sufficient irrigation to wheat was especially evident for farmers to benefit from improved nutrient inputs.

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