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Soil Properties, Crop Yield, and Economics Under Integrated Crop Management Practices in Karnataka, Southern India

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Summary. — Considering the importance of sustainable production practices with greater resource use efficiency, a study was conducted during 2009–12 to understand the soil properties, crop yield, and economics as affected by the integrated crop management (ICM) practices under the *Bhoochetana* (soil rejuvenation) program in Karnataka, India. Results from 3776 crop-cutting studies on different crops (cereals, pulses, and oilseeds) revealed that there is a vast spatial variability in case of various soil nutrients across different taluks of Karnataka. Balanced fertilizer application, both in rainfed and irrigated areas, directly influenced crop yields. Yields of cereals, legumes, and oilseeds were 3590, 1400, and 2230 kg ha^{-1} with improved management practices as compared to 2650, 1030, and 1650 kg ha^{-1} with conventional farming practices, respectively. Average net income estimated from conventional farming was Rs. 26,290 ha^{-1}, while it was Rs. 35,540 ha^{-1} from improved management practices, which indicated that ICM practices resulted in an additional 35% income. The oilseeds performed better in terms of achieving higher net income and benefit–cost ratio while the cereals and legumes also have shown significant improvement in yield compared to the yields from conventional farming practices. The detailed findings on soil properties, yields of crops, and economics suggested that there is a vast potential for crop productivity improvement through ICM practices across different soil types and rainfall zones of Karnataka, India.

Key words — soil nutrients, crop productivity, water balance, smallholder farmers, *Bhoochetana*

1. INTRODUCTION

Globally, agriculture has to produce more food from less area of land through more efficient use of natural resources in order to meet the growing demands of increasing population (Hobbs, Sayre, & Gupta, 2008). India has 141 million ha of agricultural land with a low cropping intensity of 135% (NAAS, 2009). About 54% of the agricultural land is rainfed and characterized by water scarcity, land degradation, low inputs use, and low productivity. Crop productivity of these areas oscillates between 0.5 and 2.0 ton ha^{-1} with an average of 1 ton ha^{-1} (Rockström *et al.*, 2010; Wani, Rockstrom, Venkateswarlu, & Singh, 2011b; Wani, Rockström, & Sahrawat, 2011a). Irrigated land that covers 46% of the total agricultural area contributes significantly in satisfying 55% of total food requirement of the country (GoI., 2012), but on the other hand, it consumes almost 70% of the freshwater resources and has left limited scope for further expansion of the irrigated area (CWC & Handbook of water resources statistics, 2005). Thus, the current and future food security of the country is only feasible by harnessing the huge untapped potential of rainfed agriculture through improved management of land, water, nutrients, and other natural resources (Rockström *et al.*, 2007; Wani, Sarvesh, Krishnappa, Dharmarajan, & Deepaja, 2012b; Wani, Sreedevi, Rockström, & Ramakrishna, 2009).

However, recent data show a general increase in the global food production. This can be attributed to both the expansion of cultivated area and technological progress, leading to increased crop yields (FAO, 2010). This yield gain has been achieved largely due to heavy reliance on fertilizers and pesticides, thereby putting pressure on the environment. Thus, it is clear that the current approaches to agriculture and agricultural technology are not adequate for addressing the food security issues. It is estimated that by 2025, India's population is expected to reach 1.45 billion (United Nations., 2006) and the cereal requirement will be between 257 and 296 million tons (Bhalla, Hazell, & Err, 1999; Kumar, 1998). The future food production must increase by about 5 million tons annually to ensure food and nutritional security to the increasing population (Kanwar, 2000). Therefore, there is a need recognized for further examination of the contextual factors associated with the development of new and environmentally sustainable agricultural technology (Sahrawat, Wani, Pardhasaradhi, & Murthy, 2010; Wani *et al.*, 2012b). This requires multidisciplinary approach involving farmers, researchers, and policy makers to deal with knowledge integration.

It calls for sustainable soil management for achieving food and environmental security. Investing in soil management provides opportunities for agricultural intensification and diversification of livelihood options that minimizes resource degradation (Shiferaw, Bantilan, & Wani, 2006). There is now emerging evidence that regenerative and resource-conserving technologies and practices can bring both environmental and economic benefits for farmers, communities, and nations. The best evidence comes from the countries of Asia and Africa where the concern is to increase food production despite fragmentation of land and limited use of technologies. In these complex landscapes, some farming communities adopted regenerative technologies and substantially improved their agricultural yields (Rockström *et al.*, 2007, 2010; Wani, Pathak, Jangawad, Eswaran, & Singh, 2003). These evidences have common elements, i.e., farmers have made use of resource-conserving technologies, such as soil and water conservation, integrated nutrient management, crop diversification, water harvesting, and integrated pest management. There has been action by groups and communities at the local level, with farmers becoming experts in collectively managing their farms and watersheds as ecosystems. Moreover, there

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have been supportive external government and/or non-governmental institutions, often working in new partnerships with new participatory approaches, which have reoriented their activities focusing on the local needs and capabilities (Wani, Garg, Singh, & Rockstrom, 2012a).

This study was conducted in the state of Karnataka in India (**Figure 1**), which has a large rainfed area (7.5 million ha) in the country, after Rajasthan, with diverse agroecological characteristics. Quantitative distribution of rainfall determines the growth of the agriculture sector in Karnataka as 70% of the total agricultural area comes under rainfed lands. The state's average rainfall is 1139 mm, which varies from 3085 mm in the coastal region to 593 mm in the northern dry region. Nearly half the total rainfall is received during the monsoon season (GoK, 2011). Large variability is also found in its distribution between years. In 2009, the state experienced a surplus in rainfall as most of the taluks received rainfall above the normal (taluk is an administrative sub unit of a district typically comprising number of villages). Rainfall was normal in 2010 but in 2011 and 2012 there was a deficit in rainfall. Out of 176 taluks, only seven taluks received lesser than 500-mm rainfall in 2009 whereas 101 and 127 taluks received rainfall less than 500 mm during 2011 and 2012, respectively. The rainfall analysis also shows the occurrence and severity of drought situations in the state (**Figure 2**).

Maize (*Zea mays*), rice (O*ryza sativa*), sorghum (*Sorghum bicolor*), finger millet (*Eleusine coracana*), and pearl millet (*Pennisetum glaucum*) are the major staple crops occupying more than 50% of the land area and accounting for more than 60% of the population's calorie intake (GoK, 2011). Until recently, farmers were facing four major constraints (GoK, 2011). Firstly, over the last two decades, the average productivity of the major rainfed crops was two to three times lower than the potential productivity of the state. Secondly, soil

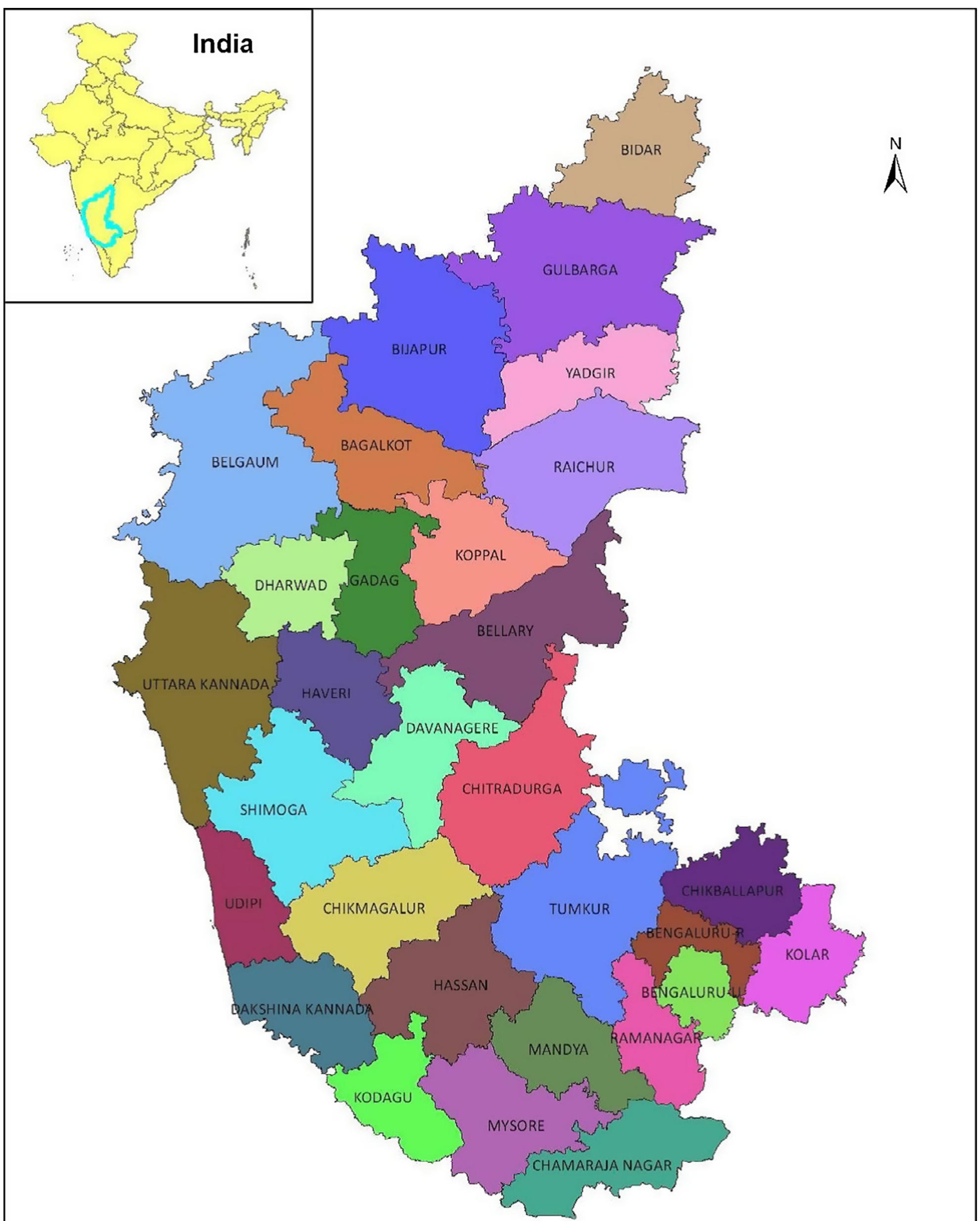

Figure 1. *Map showing all the districts in the state of Karnataka.*

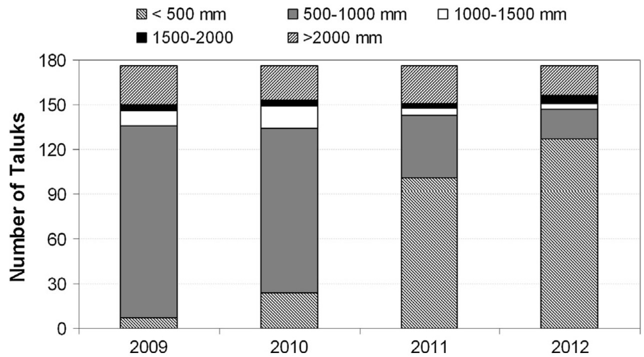

Figure 2. *Rainfall variability across the state during 2009–12.*

degradation due to continuous monocropping and insufficient recycling of the organic matter, coupled with rainfall variability and frequent dry spells resulted in low crop yields (GoK, 2011; Sahrawat *et al.*, 2010; Singh *et al.*, 2009; Wani *et al.*, 2012a). There has been increasing realization that the solution for maintenance and improvement of soil fertility cannot be made solely through the use of organic and inorganic fertilizers. However, reducing soil degradation only through inorganic fertilizer is not adequate. Due to imbalance between nutrient supply and extraction over the period, soil has been depleted in essential nutrients. Hence, soil-test-based micronutrient application along with biofertilizers and improved cultivars were introduced that made a huge impact on the crop yield, even if the rainfall is below average (Raju, Wani, & Anantha, 2013; Wani *et al.*, 2012a). Thirdly, smallholder farmers have limited access to farm inputs such as fertilizers, micro and secondary nutrients, and seeds due to their weak purchasing power and lack of market infrastructure. In some instances, the price offered by the state in terms of minimum support price is low in comparison to the cost of production, thereby providing little incentive to the farmers to produce above subsistence level. Fourthly, land fragmentation, which is increasing due to increase in number of nuclear families coupled with labor scarcity in the predominantly cereal-based farming systems, has become a critical issue. Considering all these constraints, *Bhoochetana* (soil rejuvenation) program was implemented with an overall objective of improving agricultural productivity in the state. This paper describes *Bhoochetana* program and reports the results of effects of integrated soil and crop management practices on crop yield and profitability. We compared the crop yields obtained from conventional farming practice (FP) with the improved management practices (IP).

2. *BHOOCHETANA*: SCIENCE-LED PARTICIPATORY APPROACH TO BRIDGE THE YIELD GAPS

This approach emerged from the lessons learnt from long-term watershed-based research led by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Telangana, India and national partners (Wani *et al.*, 2003). This interdisciplinary research, over the years, has shaped up into an Integrated Genetic and Natural Resource Management (IGNRM) approach at ICRISAT (Twomlow, Steyn, & du Preez, 2006; Wani *et al.*, 2012a). After realizing the importance and potential of combining disciplinary expertise in a complementary way, the idea of consortium approach based on the success of multidisciplinary approach was adopted. Consortium is a convergence of agencies/actors/stakeholders who have a significant role to play in the watershed development project (Shambu Prasad, Hall, & Wani, 2005; Wani *et al.*, 2003). Facilitated by a leader/leading organization, member-organizations prepare common plans and work toward achieving the agreed common objectives. This approach was first adopted during 1999, when the Asian Development Bank came forward to support ICRISAT's idea of testing the consortium model in Adarsha Watershed in Kothapally village, Ranga Reddy district, Telangana, India. Firstly, the aim was to minimize the gap between the research findings and on-farm developments (Garg, Karlberg, Barron, Wani, & Rockstrom, 2012; Garg & Wani, 2012). Secondly, the purpose was also to adopt the learning loop in the planning of strategic research based on the participatory research and development system. The integrated watershed management model has demonstrated that with proper management of natural resources, the system's productivity can be enhanced and poverty can be reduced without causing any further degradation of the natural resource base. The scaling-up of these innovations has been attempted in countries like India, Vietnam, Thailand, and China (Wani *et al.*, 2012a).

Bhoochetana mission project is a scaling-up project based on the principles of convergence, consortium, capacity building, and collective action (Wani *et al.*, 2012a). The project idea was first discussed by ICRISAT scientists and presented to the government of Karnataka. In 2009, ICRISAT was invited to form a consortium with state agricultural universities, line departments such as Department of Agriculture (DoA), Watershed Development Department, Directorate of Economics and Statistics (DES), community-based organizations, and farmers for the project. The consortium collectively took part in planning and promoting the project activities. The project activities were designed for six districts of Karnataka during the first year. It was up-scaled to 16 districts (including six districts of first year) during the second year. After realizing the success, the project activities were up-scaled to the entire state with 30 districts in the third year. The project *Bhoochetana*, then became a mission project for the government and the role of the consortium was changed to an advisory board. A high-level coordination committee was formed at the state level for regular monitoring and evaluation of the project activities.

Launched in 2009, it was the first DoA project to systematically involve knowledge-generating institutes like universities and ICRISAT. The purpose was to reach millions of smallholder farmers in the rainfed region to adopt need-based nutrient application for improving crop productivity. With technical backstopping by ICRISAT, DoA officers stationed at districts, taluks, and *Raitha Samparka Kendras* (farmers' contact centers) visited all the participating farms regularly. During the visits, DoA officers not only discussed and monitored the soil fertility management, pest and disease management, and crop-related issues, but also provided opportunities for building relation and mutual trust with the farmers. The farmers participated in the project on an individual basis and adopted the land rejuvenation interventions, while DoA provided extension services and inputs (seeds, micro and secondary nutrients) with 50% incentives.

The status of soil nutrient deficiency was mapped by adopting stratified soil sampling and to further recommend crop-specific nutrients based on the taluk-level soil-test results (Sahrawat, Rego, Wani, & Pardhasaradhi, 2008). The innovativeness of this project was to improve the knowledge base of farmers about the status of their soil nutrients and adopt corrective measures to address the yield gaps. In this process, farmers were involved in collecting soil samples and to undertake participatory demonstrations of need-based fertilizer application including micro and secondary nutrients along with improved management practices (for example, improved cultivars and seed treatment). Further, this process was strengthened by providing 50% incentives on the inputs supply. Prior to the implementation of *Bhoochetana*, DoA was following the fertilizer recommendations that were common for the entire state despite large variability in soil fertility status. However, based on the soil-test results, the required quantity of fertilizers and other inputs in the targeted taluks and districts were estimated well in advance and made available in packages.

The major weakness of the scaling-up technology was poor extension system. To address this issue, the innovative extension system of "farm facilitator" (local para-professional extension worker) was introduced. These farm facilitators were progressive farmers who have practiced agriculture and have minimum academic qualification. Based on these criteria, DoA selected nearly 10,000 farm facilitators on honorarium basis. A week-long institutional training was provided to update their knowledge about the technologies and build their capacity. Universities have played an important role in building the capacity of the farm facilitators by organizing regular training programs. Moreover, *Bhoochetana* program was popularized through village meetings, mass media, and wall writings across the districts. State and central agricultural programs were also converged through *Bhoochetana*.

3. MATERIALS AND METHODS

(a) *Soil nutrients mapping*

The large tracts of semi-arid region in India witnessed soil nutrient deficiencies that resulted in low crop yields (Sahrawat *et al.*, 2008). On recognizing this fact, the *Bhoochetana* mission project was aimed at characterizing the fertility status of soils as an entry point. By adopting the statistically proven random stratified sampling method (Sahrawat *et al.*, 2008), about 92,900 soil samples were collected from farming fields of 30 districts covering about 3.73 million ha in Karnataka by 2012. The samples collected represented a huge spatial variability in terms of rainfall, topography, cropping system, farm size, and its management. Soil samples were analyzed in the state-of-the-art laboratory. A range of soil health parameters, i.e., organic carbon, availability of nutrients like phosphorus (P), potassium (K), zinc (Zn), boron (B), sulfur (S), soil pH, and electrical conductivity (EC) were analyzed, and the data were used to develop taluk-level fertilizer recommendations in contrast to the conventional blanket recommendations for macronutrients at the state level. The basic idea of this program was to recommend full dose of a particular nutrient if more than 50% of farming fields were found deficient and half dose if less than 50% of the fields were found deficient in that particular nutrient. The DoA was empowered to adopt and disseminate soil-test-based results and site-specific fertilizer recommendations through traditional and innovative means of extension. Based on the region-specific constraints, a package of improved soil–crop–water management practices was designed and shared among the consortium partners and stakeholders.

(b) *Farmers' participatory field experiments*

The study was conducted in all the 30 districts of Karnataka for four years in a phased manner. Major crops in the taluks were identified and farmers' participatory field demonstrations with a minimum area of 0.2 ha were conducted. Altogether, a total of 3776 on-farm trials were undertaken during 2009 to 2012. These fields were selected based on the farmers' willingness, which were later divided into two parts, i.e., IP and FP. Improved crop cultivars (**Table 1**) and seed treatment along with a balanced fertilizer dose were applied under the IP whereas control plots were cultivated as per the conventional practices. The demonstration trials in all the districts were managed by the farmers themselves with support from extension staff of DoA and Krishi Vigyan Kendras while research technicians of ICRISAT provided recommendations on the management of the plots. Scientific knowledge was provided by scientists and research technicians located at the districts for liaising with the farmers, farm facilitators, and DoA.

(c) *Harvest measurements*

Crop and biomass yields were estimated by adopting the standardized Crop Cut Method. At physiological maturity, the entire plant biomass was harvested from 3 x 3 m^2 area from both FP and IP. Nearly 10 such crop-cutting experiments were conducted in each taluk representing the major cropping pattern. The collected plant samples were dried in an oven at 65 °C and yields were calculated. The Crop Cut Method (Tek *et al.,* 2016) was used to measure crop yield and biomass production. Cropping systems in Karnataka are very diverse and a large number of crops are grown; however, in this paper, we have selected few important crops (maize, rice, finger millet, pearl millet, sorghum, chickpea, green gram, pigeonpea, soybean, and groundnut) to understand the impact of *Bhoochetana*. Crop productivity measured from the Crop Cut Method under IP was compared with FP for four years.

(d) *Crop production functions*

Crop production functions (rainfall vs. crop yields) were derived for major cereals (maize, rice, finger millet, pearl millet, and sorghum), oilseeds (groundnut and soybean), and legumes (pigeonpea, chickpea, and green gram) by describing the crop sensitivity with reference to water availability and its interaction with nutrient management. The Food and Agriculture Organization of the United Nations (FAO) described the linear relationship between crop yield and irrigation to an optimum threshold, where relative yield reduction is related to the corresponding relative reduction in water availability for irrigation of crops (Doorenbos & Kassam, 1979; Lovelli, Perniola, Ferrara, & Tommaso, 2007; Stewart, Cuenca, Pruitt, Hagan, & Tosso, 1977) as shown in Eqn. (1).

$$\left(\frac{\mathrm{Y_x} - Y_a}{Y_x}\right) = K_{\mathrm{y}}\left(\frac{\text{Available water}}{\text{Actual water need}}\right) \quad (1)$$

where Y_x and Y_a are the maximum and actual yields, respectively; and K_y is the correlation or proportionality factor between the related productivity loss (Lovelli *et al.*, 2007). In this study, production function for selected crops is established from the large-scale farmers' field data during 2009–12.

(e) *Analyzing impact of Bhoochetana*

(i) *Crop yield and water productivity*

Crop water productivity (WP) is the amount of grain yield obtained per unit of water (Tuong & Bouman, 2003). Depending on the type of water sources considered, WP is expressed as grain yield per unit water evapotranspired (WP_{ET}) or grain yield per unit total water input (effective rainfall under rainfed

Table 1. *Characteristics of improved crop cultivars demonstrated in Bhoochetana*

Crop	Variety/hybrid	Duration (days)	Major characteristics
Groundnut	ICGV 91114	95–100	Short-duration having 52% oil content, 17% protein, and resistance to intermittent and terminal droughts
Groundnut	ICGV 0350	110–115	Drought tolerant
Groundnut	ICGV 0351	100–115	Drought tolerant
Groundnut	ICGV 2266	110–115	Drought tolerant
Groundnut	Kadiri 9	115–125	Medium tall plant with green obtuse leathery leaves suitable for drought prone area
Pigeonpea	ICPH 2740	180–190	Medium-duration, fusarium wilt and sterility mosaic resistant, cytoplasmic male sterility based hybrid
Pigeonpea	ICP 8863 (Maruthi)	150–160	Fusarium wilt resistant
Pigeonpea	ICPL 87119	150–170	Fusarium wilt and sterility mosaic resistant, cytoplasmic male sterility based hybrid
Pigeonpea	ICPL 7035	200–210	Fusarium wilt and sterility mosaic resistant
Pigeonpea	ICPL 88034	135–140	Suitable for drought prone areas and also for intercropping with groundnut and finger millet
Pigeonpea	ICPL 161	125–135	Short-duration indeterminate variety
Pigeonpea	ICPL 88039	120–125	Extra short-duration line suitable to cultivate as sole or inter-cropped with finger millet and groundnut; tolerant to drought and due to earliness it escapes insect damage
Sorghum	CSV 17	85–90	Early-maturing variety, moderately resistant to shootfly, stem borer, rust, anthracnose, leaf spots, sugary disease (ergot), and charcoal rot
Sorghum	PVK 801	115–120	Resistant to leaf diseases and remains green at maturity. It has high grain iron (40 ppm) and zinc (21 ppm)
Sorghum	CSV 27	110–115	Medium-duration tolerant to shootfly, resistant to leaf diseases and remains green at maturity; dual purpose, non-lodging variety
Sorghum	CSV 23	110–115	Medium-duration variety and tolerant to shootfly, resistant to leaf diseases, and remains green at maturity; dual purpose non-lodging variety
Sorghum	CSH 24MF	110–120	Early maturing multi-cut hybrid
Green gram	LGG 460	65–70	Short duration and high yielding
Green gram	SML 668	60–65	Fair degree of tolerance to mung bean yellow mosaic
Green gram	IPM 02–14	62–66	Resistant to mung bean yellow mosaic virus and leaf crinkle
Finger millet	MR 1	120–130	Drought tolerant variety
Finger millet	GPU 28	110–115	Resistant to fungal infestations
Pearl millet	ICTP 8203 Fe (Dhanashakti)	75–80	Resistance to Downy mildew and tolerance to drought
Soybean	JS 335	85–90	High yielding
Soybean	JS 9560	90–95	High yielding
Rice	BPT 5204	140–150	Susceptible to blast
Rice	RNR 15048	130	Short duration and suitable to post-rainy season
Rice	Jagtyal masuri	140–145	Resistant to blast, high yielding

condition). In this study, physical WP of IP and FP were calculated using the simulated values of evapotranspiration (ET_a) and yield values obtained for selected cereals, oilseeds, and legumes from the entire state (Eqn. (2)).

$$WP_{ET}(kg/m^3) = \frac{\text{Grain yield(kg)}}{ET_a(m^3)} \quad (2)$$

Moreover, economic water productivity (EWP) (Rs m^{-3} of water) was also derived using the net income obtained against per unit of water input used in the production process (Eqn. (3)).

$$EWP(Rs/m^3) = \frac{\text{Net income(Rs.)}}{ET_a(m^3)} \quad (3)$$

(ii) *Economic analysis*

Economic performance of the system was assessed using the standard benefit–cost (BC) ratio analysis to determine production cost and profitability. Cost-benefit analysis is a systematic process for calculating the benefit and cost of the development project and is considered as an important indicator for assessing the economic feasibility of the targeted interventions. We considered direct benefits (increased agricultural income) due to project interventions compared to control plots. Gross income generated from the agricultural outputs (crop yield) was estimated using the market price. Subsequently, net economic returns were calculated by subtracting the cost of cultivation from the gross income. The additional income due to *Bhoochetana* interventions was derived by subtracting the net income of FP and IP. Further, the additional BC ratio was estimated from additional net income and additional investment on micro and secondary nutrients. In order to estimate average values for FP and IP, boxplots were used to identify extreme cases and outliers for major crops. The net income per ha from crop production was defined as gross returns minus the variable cost (Eqn. (4)).

$$\text{Net income}(Rs.ha^{-1}) = Gross\ income(Rs.ha^{-1}) - Cost\ of\ cultivation(Rs.ha^{-1}) \quad (4)$$

In addition, secondary data at different spatial and temporal scales were gathered from different departments and institutes in the state. Daily rainfall of all the taluks was collected from

Karnataka State Natural Disaster Management Centre, Bangalore during 2009 and 2012. Soil physical properties related to texture and water retention parameters at taluk levels were obtained from soil samples collected from different taluks and also from National Bureau of Soil Science and Land Use Planning database. The market price and cost of cultivation was taken from the DES, Government of Karnataka. Detailed data of the total fertilizer consumption (macro and micro) and the area coverage under *Bhoochetana* program was collected each year from the DoA, Government of Karnataka.

4. RESULTS

(a) *Soil nutrient mapping*

Soil fertility analysis was an entry point activity under *Bhoochetana* initiative, which was useful in determining the deficiency levels and taking corrective measures to increase the crop yield as well as cut the cost of fertilizer overdosing. **Figure 3** shows the spatial variability of different soil nutrients for different taluks of the state. It was found that soils are deficient largely in micro and secondary nutrients like Zn, B, and S. Deficiency of P was also found largely in the north western districts of Karnataka. Test results showed that the soil lacks organic matter that largely varies from 0.25 to 0.50%. The Western Ghats are found relatively good in soil organic carbon, which could be due to large forest, humid environment, and crop plantation area. Moreover, soils in the Western Ghats are found to be acidic in nature due to heavy rainfall. The soil pH is found increasing from West to East and South to North direction as per the changing rainfall pattern. Interestingly, the diagnosis revealed that most of the farms had secondary and micronutrient deficiencies, i.e., 52% in S, 55% in Zn, and 62% in B. Deficiencies of S, B, and Zn are more widespread than the mostly focused macronutrients, i.e., P and K, which are apparently holding back the productivity potential in the semi-arid tropics. Soil health mapping was the first important output of the *Bhoochetana* project, which convinced stakeholders to apply for crop- and site-specific nutrient application rather than following the state-level blanket fertilizer recommendations.

(b) *Impact of improved management practices on crop yield*

(i) *Crop yield*

The on-farm trials managed by farmers showed significant differences between FP and IP (**Figure 4**). With IP, the crop yield increased by 30 to 60% compared to FP. However, the crop productivity decreased with decrease in rainfall from 2009 to 2012, but the yields from IP were consistently higher compared to FP even during the lower rainfall years of 2011 and 2012.

Average maize grain yields were 5500 and 7600 kg ha^{-1} in 2009; and 3900 and 5100 kg ha^{-1} in 2012 under FP and IP, respectively. A large variation in crop productivity (maximum to minimum range) was recorded during the dry years compared to wet and normal years. High maize yield was obtained where supplemental irrigation was provided otherwise crop yields were poor due to water stress situation in rainfed areas. Finger millet, a drought-tolerant crop largely grown in southern part of Karnataka, recorded average grain yield of 1750 and 2700 kg ha^{-1} in 2009; and 1250 and 1680 kg ha^{-1} in 2012 under FP and IP, respectively. Grain yield, however, decreased from 2009 to 2012, but IP helped farmers to harness better yield despite high water stress condition. Chickpea, a post-monsoonal crop which is generally grown with residual soil moisture, also showed better yield under IP compared to FP, but this difference decreased with increase in soil moisture stress, especially in 2012. Average chickpea grain yields were 1050 and 1400 kg ha^{-1} in 2009; and 600 and 780 kg ha^{-1} in 2012 under FP and IP, respectively. Average groundnut yield in first three years (2009–11) were almost 1300 and 1800 kg ha^{-1}, but dropped significantly to 600 and 780 in 2012 under FP and IP, respectively.

(ii) *Crop yield response with rainfall*

To understand yield sensitivity with monsoonal rainfall, the average yield measured in different taluks were plotted with rainfall for important cereals (rice, maize, pearl millet, finger millet, and sorghum), legumes (chickpea, greengram, and pigeonpea), and oilseed crops (soybean and groundnut) both under FP and IP (**Figure 5** and **Figure 6**). In general, crop yield increased with an increase in rainfall amount but vast variability was recorded even in the same rainfall class. This variability is due to the variation in rainfall distribution, soil types (nutrient status, moisture holding capacity, etc.), and management factors (fertilizer input, time of sowing, etc.) among the taluks.

Rice is largely grown under irrigated condition, but is also grown under rainfed condition where rainfall is high. As we have not acquired total water inputs (rainfall plus irrigation) for rice, it is least important to analyze the crop yield with rainfall. Importantly, rice yields under IP were found higher (Student t-test, $P < 0.001$, nearly 600–1000 kg ha^{-1} additional as shown by trend line) than FP, which also indicated the importance of integrated crop management practices in the higher yielding scenarios. Data collected from a large number of demonstrations showed that maize yield, generally increased with an increase in rainfall. Similar to rice, farmers also applied supplemental irrigation for maize, as it is a water-demanding crop relative to other dryland crops. Relatively moderate-to-higher grain yield in poor rainfall scenarios (200–300 mm) indicated the need for supplemental irrigation. Irrespective of irrigation inputs, maize yield with IP was 800 to 1500 kg ha^{-1} higher ($P < 0.001$) than FP (**Figure 5**). Farmers in Karnataka generally cultivate pearl millet, finger millet, and sorghum in low-rainfall regions (less than 800 mm). Yields of these crops also increased with better water availability, and 500 to 800 kg difference in crop yield was observed between FP and IP ($P < 0.001$). Similar observations were also recorded for legumes and oilseed crops (**Figure 6**).

Further, yields for every 100-mm rainfall range was grouped together and averaged. Productivity functions for selected cereals, legumes, and oilseeds were developed (**Figure 7** and **Figure 8**). Linear trend was found in maize productivity with an increase in rainfall up to a threshold point (900–1000 mm) whereas pearl millet and finger millet crops increased linearly up to 600–700 mm but declined with an increase in rainfall indicating that these crops are resilient in dry climatic conditions. Production function developed for legume crops (chickpea, green gram, and pigeonpea) and oilseed crops also showed strong linear response with an increase in rainfall, as shown in **Figure 7**.

(iii) *Spatial variability of crop yield and income*

Spatial variability in cereal productivity among different taluks was analyzed. Yields obtained from cereal crops under FP and IP for 2012 are shown in Figure 9a and Figure 9b, respectively. Additional net income and additional BC ratio due to IP are also depicted for the same year in Figure 9c and Figure 9d, respectively. Some of the plotted data are

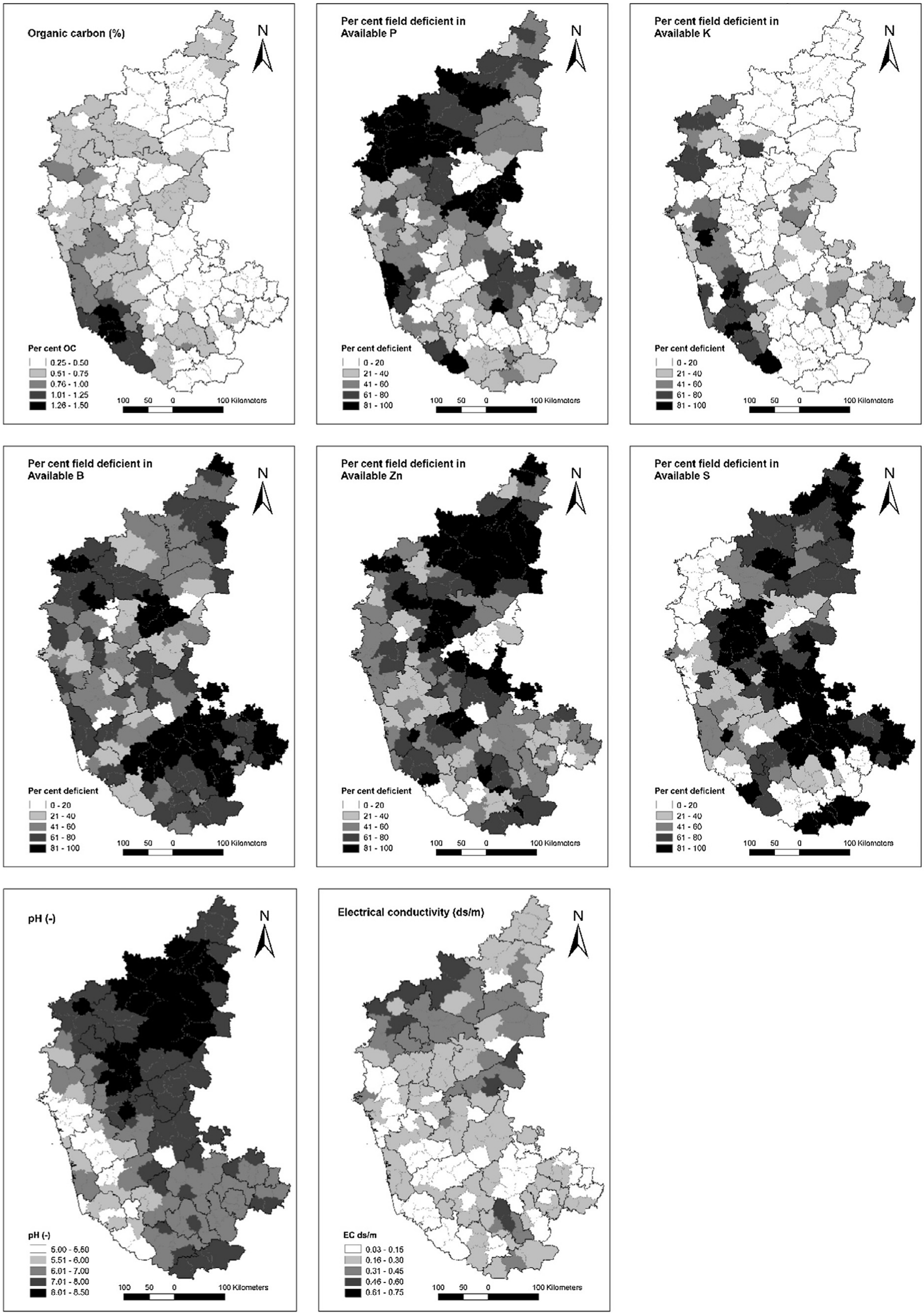

Figure 3. *Percent field deficient in organic carbon, available P, available K, available B, available Zn, and available S in different taluks of Karnataka state.*

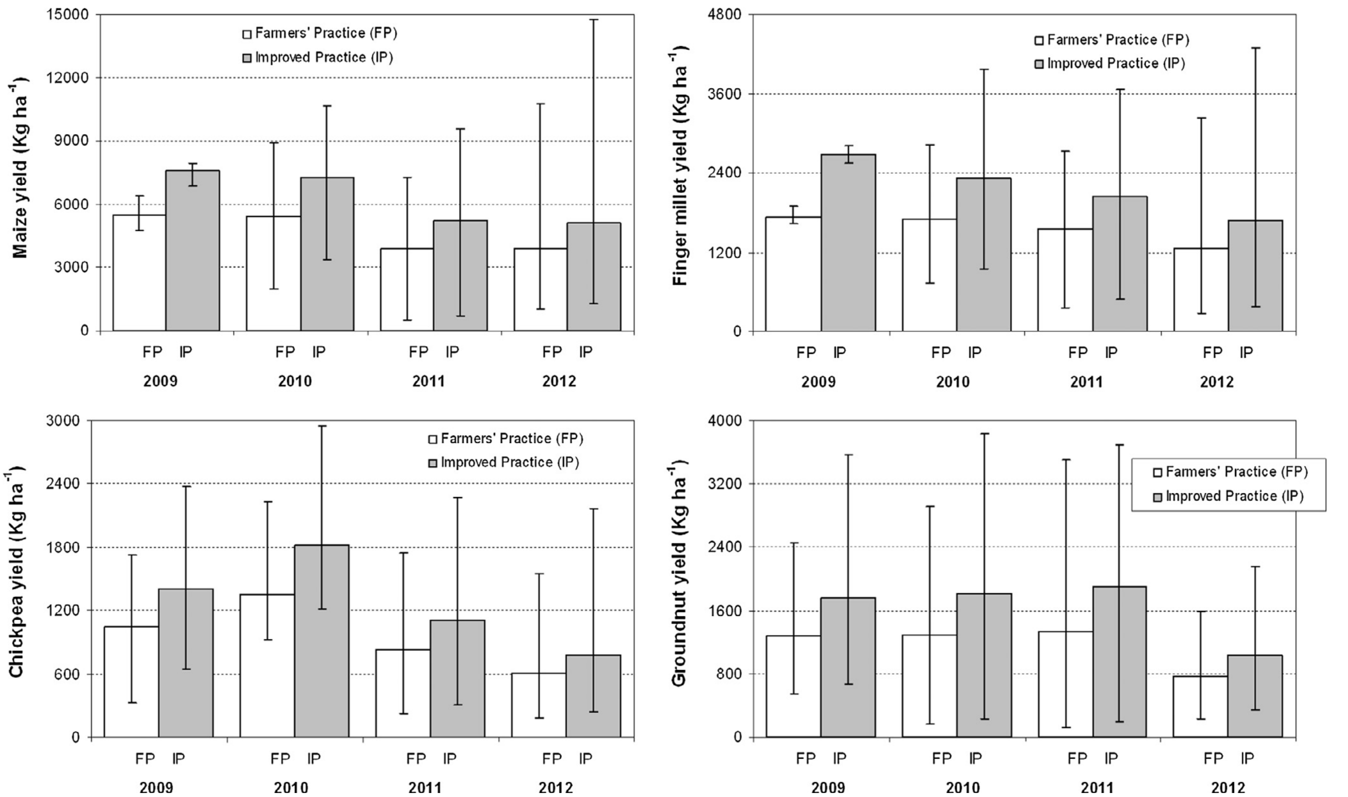

Figure 4. *Comparison of crop yield of maize, finger millet, chickpea, and groundnut between improved practice and conventional farming practice from 2009 to 2012. Columns show average yields obtained from different crop-cutting experiments and error-bars show the maximum and minimum range.*

hidden into down layers as the numbers of GIS (geographical information system) layers are overlaid for different crops; however, the figure depicts a comprehensive overview of the cropping system. Rice is largely found in high-rainfall zones such as western part of Karnataka and hilly (*Ghat*) regions, where the annual rainfall is higher than 1500–2000 mm. Maize is cultivated in the central part of Karnataka largely spread from North to South districts. Pearl millet and sorghum are cultivated in northern part and finger millet in Southern Karnataka districts. Results showed that IP helped in enhancing crop productivity to the next level or further higher as depicted by various color intensities in most of the taluks compared to FP. As a result, farmers benefited with minimum additional income of about Rs. 2500 ha^{-1} to maximum of Rs. 30,000–35,000 ha^{-1}. The additional net income was maximum in maize cultivation followed by rice and pearl millet. Furthermore, the additional BC ratio was in the range of 3 to 9 indicating significant returns from IP. Similar results were also depicted for legumes and oilseed crops in Figure 10.

(c) *Profitability analysis*

(i) *Crop yield and net income*

Table 2 compares the crop yield, net additional income and BC ratio between FP and IP in different years in Karnataka. To compare the economic benefit from different crops, we have presented net additional income after subtracting the cost of cultivation from the gross income both from FP and IP. The results are most revealing. Maize, pigeonpea, and groundnut are more remunerative during normal rainfall year of 2010, as the yield of these crops ranged between 7275 and 5435 kg ha^{-1}, 1630 and 1210 kg ha^{-1}, and 1810 and 1300 kg ha^{-1} under IP and FP, respectively. The increased yield resulted in enhanced net additional income of Rs. 14,460 ha^{-1}, Rs. 10,630 ha^{-1}, and Rs. 10,160 ha^{-1} from maize, pigeonpea, and groundnut, respectively. On the other hand, other rainfed crops such as chickpea, soybean, and black gram also performed better as the median yield increment was around 35% resulting in an increase in net income of Rs. 6,596 ha^{-1}, Rs. 7,335 ha^{-1}, and Rs. 7,784 ha^{-1} under moderate-to-good rainfall conditions. In all the cases, the improved interventions helped in improving the profitability by 32–42%.

During the dry year of 2011, the crop yields of maize, pigeonpea, groundnut, and rice increased significantly in FP but a declining trend was observed compared to yields in 2010. The net additional income obtained from IP was Rs. 11,830 ha^{-1}, Rs. 9,560 ha^{-1}, Rs. 14,160 ha^{-1}, and Rs. 10,595 ha^{-1} for maize, pigeonpea, groundnut, and rice, respectively. The same trend was observed during 2012 (very dry year), when the net income was reduced in comparison to 2011 for groundnut (Rs. 8,160 ha^{-1}) and pigeonpea (Rs. 7,750 ha^{-1}), but increased marginally for maize (Rs. 13,510 ha^{-1}) and rice (Rs. 11,040 ha^{-1}). The effect of declining rainfall was more evident in all the years, except in green gram and soybean, and the yield of all other crops was reduced by almost 21–133% under IP when compared between normal (2009) and very dry (2012) years. However, the IP helped in withstanding the shock and subsequently increased the net income.

Average crop yields over the four-year period were 1,810 and 2,440 kg ha^{-1} under FP and IP, respectively. Similarly, an average net income of Rs. 26,290 ha^{-1} was estimated from FP and Rs. 35,540 ha^{-1} from IP, which indicated an additional 35% income by IP. Physical WP under FP and IP was 0.51 kg m^{-3} and 0.69 kg m^{-3} whereas EWP was 5.3 Rs. m^{-3} and 7.15 Rs. m^{-3}, respectively.

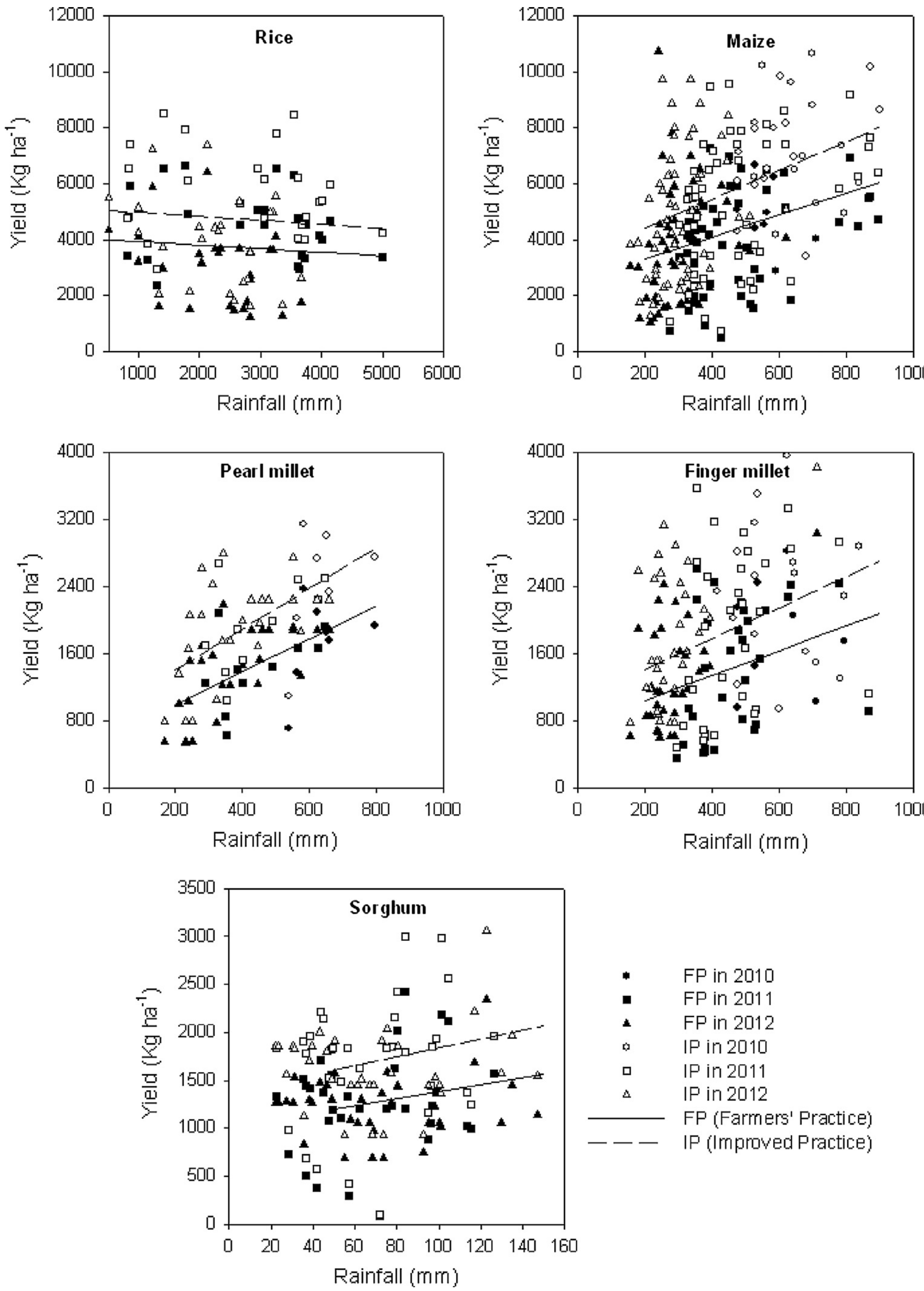

Figure 5. *Response of crop yield with rainfall and balanced fertilizer application for selected cereals (rice, maize, pearl millet, finger millet, and sorghum) across the state of Karnataka during 2010 to 2012. Dark symbols represent crop yield under farmers' practice and open symbols represent crop yield under improved practice; smooth and dotted lines show trend line (yield response) with increasing rainfall amount under farmers' practice and improved practice, respectively.*

(ii) *Benefit–cost ratio*

Table 2 compares the return on investment between IP and FP for four years from 2009 to 2012 and revealed that IP performed better in terms of return on investment (BC ratio) during all the years. The mean additional BC ratios for 2010, 2011, and 2012 for major crops (chickpea, groundnut, maize, pearl millet, pigeonpea, green gram, finger millet, sorghum, soybean, and rice) were 5.7, 5.4, 6.2, and 5.6, respectively. Interestingly, IP has contributed to enhancement of BC ratio above the mean level for maize (9.1), pigeonpea (7.9), and groundnut (6.7) during 2010, while the same crops performed low during 2012 due to poor rainfall. The BC ratio ranged from 3 to 9 depending on the crop, soil type, and rainfall condition. The comparison of IP with FP revealed that such improved management systems perform better in terms of achieving higher return on investment of above 2.3:1 by IP compared to 1.9:1 by FP even with the full cost (without considering incentives) of cultivation over the period of four years.

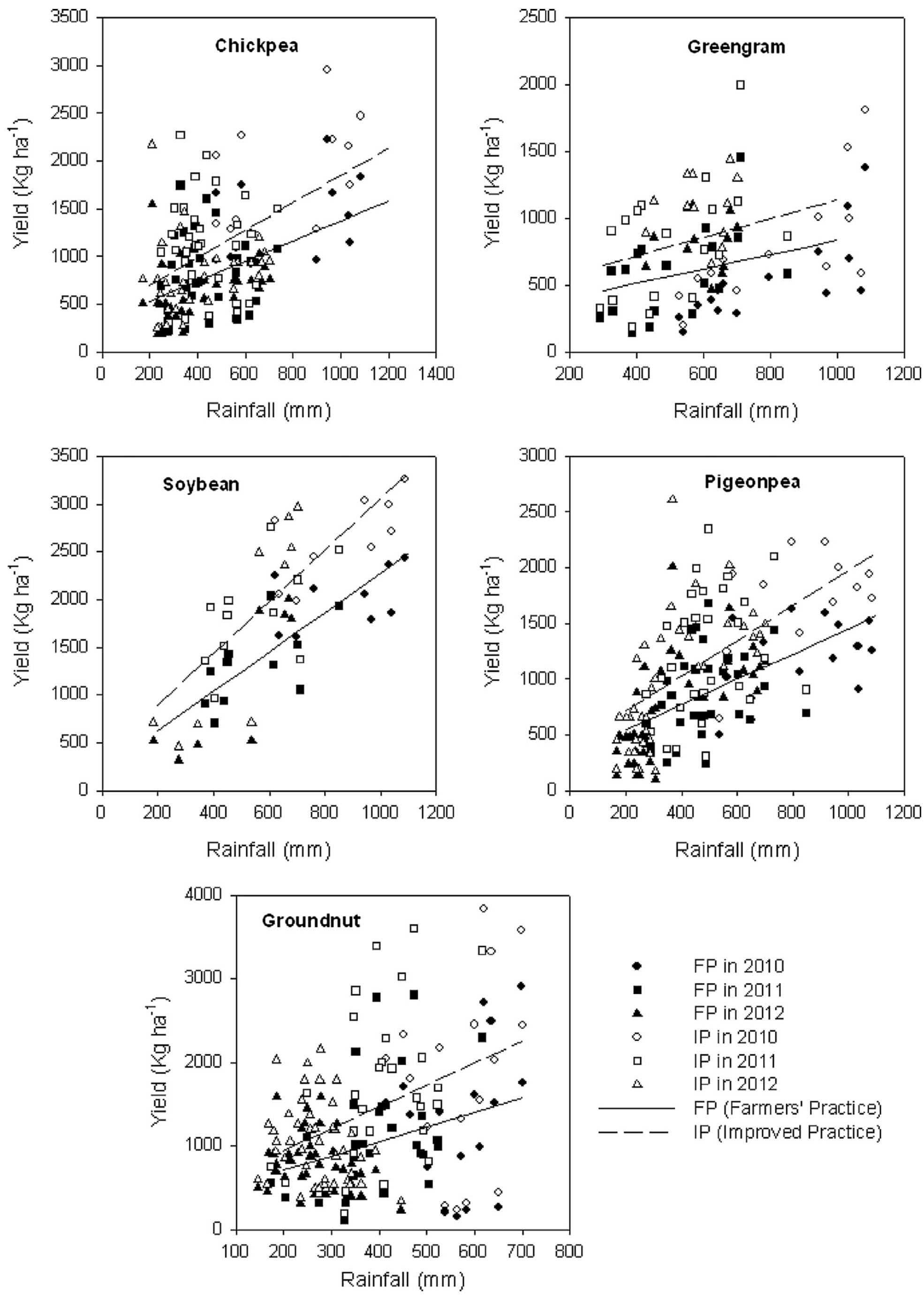

Figure 6. *Response of crop yield with rainfall and balanced fertilizer application in selected legumes (chickpea, Green gram, and pigeonpea) and oilseed (soybean and groundnut) across the state of Karnataka during 2010 to 2012. Dark and open symbols indicate crop yields under farmers' practice and improved practice respectively; smooth and dotted lines show trend line (yield response) with increasing rainfall amount under farmers' practice and improved practice, respectively.*

Table 3 presents the results of the literature survey, including outliers, showing the levels of net income and BC ratio from rainfed cropping with and without improved technologies in different regions of India. The net income obtained by adopting improved management practices has increased by 147% in different crops over the stipulated period. The return on investment of the system in different regions also showed a significant difference between FP and IP. The average BC ratio was 1.7 for FP and 2.4 for IP, respectively. These results are consistent with *Bhoochetana* results, where the overall BC ratio for FP and IP are 1.9:1 and 2.3:1, respectively. However, the additional BC ratios due to improved management practices are above 6:1 for the four-year period in *Bhoochetana*. This suggests that the integrated approach including the soil-test-based fertilizer application, new seed varieties, and IP measures has the potential of producing higher returns on investment as compared to any other single management approach.

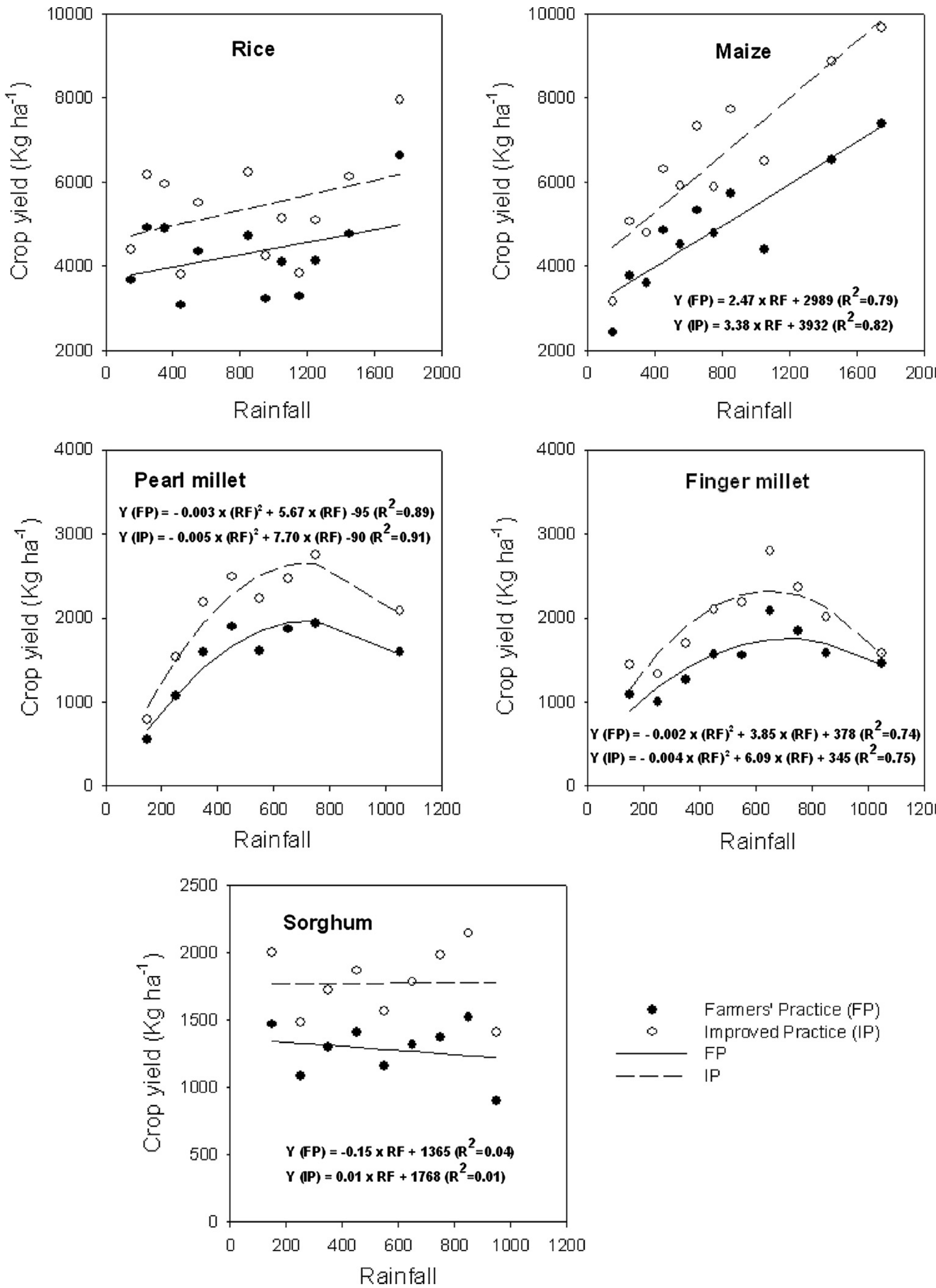

Figure 7. *Crop production function of major selected cereals (rice, maize, pearl millet, finger millet, and sorghum) obtained by averaging the large-scale crop-cutting data under different rainfall classes with every 100-mm increment. Dark circles represent crop yield under farmers' practice and open circles represent crop yield under improved practice; smooth and dotted lines show trend lines of crop yields with increasing rainfall amount under farmers' practice and improved practice, respectively.*

5. DISCUSSION

Karnataka, which suffered from poor agricultural growth before 2009, has been transformed by implementing the *Bhoochetana* program. Agriculture and allied sectors contributed to the gross state domestic product (GSDP) of Karnataka by around 17% in 2009–10. Despite the diminishing share in GSDP, agriculture still remains the main source of livelihood for 60% rural population and raw material for a large number of industries and therefore remains as a high-priority area to improve the livelihoods of millions of farmers. Soil health mapping, the entry point activity in *Bhoochetana*, identified in the state on large-scale widespread deficiencies of multiple nutrients, mainly micro and secondary nutrients and sufficiency of K and P in many areas that provided an entry point to unlock the potential of rainfed agriculture and convince the farmers with its tangible economic benefits (Raju *et al.*, 2013; Wani *et al.*, 2011). On considering the essentiality of nutrients, these conventional farming practices were apparently found holding back the realization

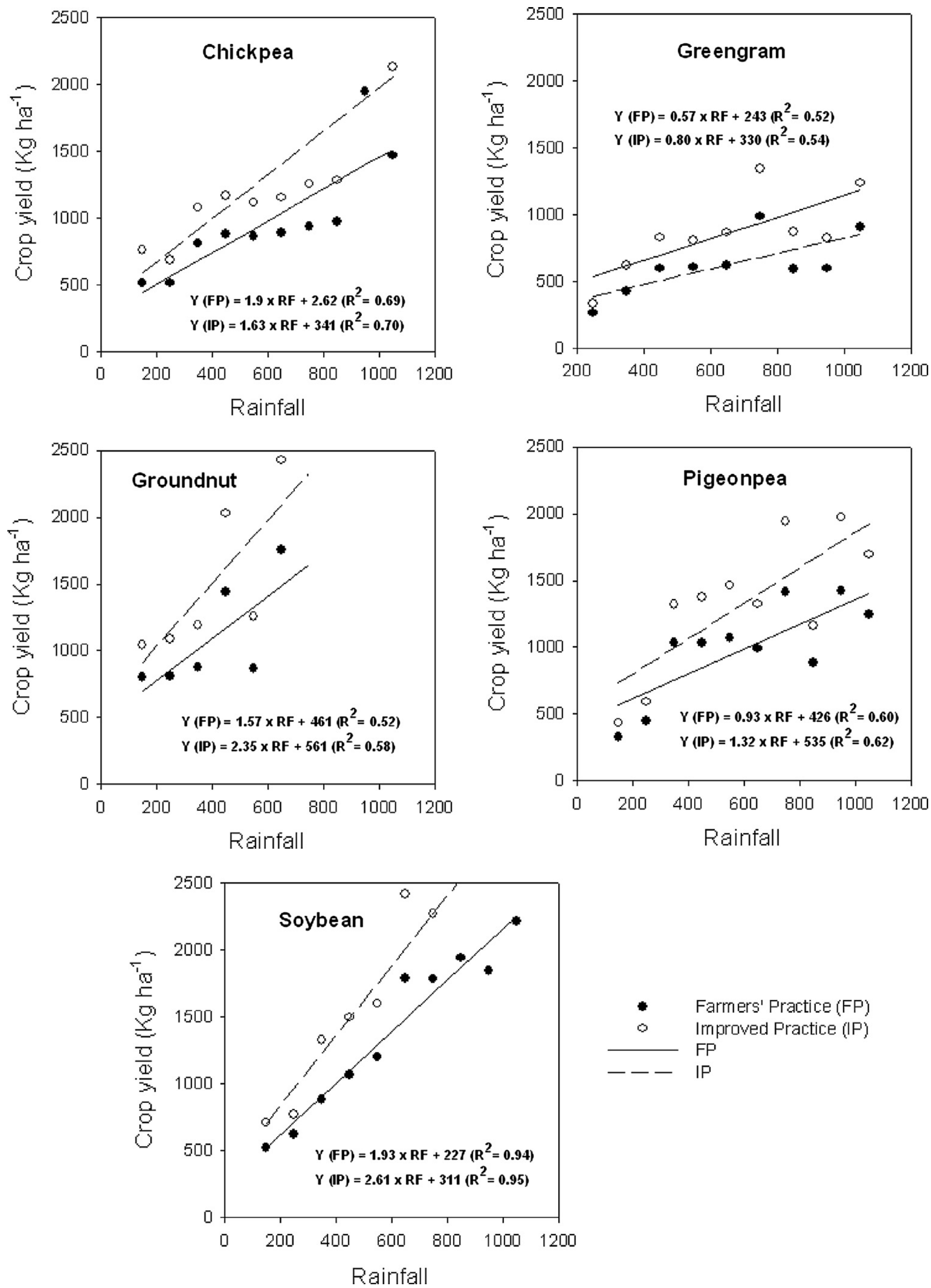

Figure 8. *Crop production function of major selected legumes (chickpea, green gram, and pigeonpea) and oilseed crops (soybean and groundnut) obtained by averaging large-scale crop-cutting data under different rainfall classes with every 100-mm increment. Dark and open circles represent crop yield under farmers' practice and improved practice; smooth and dotted lines show trend lines of crop yields with increasing rainfall amount under farmers' practice and improved practice, respectively.*

of higher yields. But, on a quest to get higher yields, farmers in many parts of Karnataka started adding more than required amount of tested macronutrients like nitrogen (N), P, and K, even though there was no deficiency of these nutrients. Such indiscriminate use of increased level of NPK resulted not only in nutrient imbalance in soils but also increased the cost of cultivation (ranging from Rs. 1000 to 5000 ha^{-1}) without increasing the crop yields. It also polluted the environment (Rajendra, 1999, 2009; Shamim & Kurosawa, 2011; Savci, 2012; Vinod, Chandramouli, & Koch, 2015). Soil health mapping indicated that the individual nutrient deficiencies were scattered differently, and thus provided a basis to design new fertilizer recommendations at village and taluk levels as against the current state-level blanket fertilizer recommendations to meet the varied soil fertility needs. The secondary and micronutrients were also included in the recommendations, while their amounts were also optimized as per the soil-test values.

In general, rainfed agriculture is considered as one-ton agriculture with a perception of less scope to increase the yield.

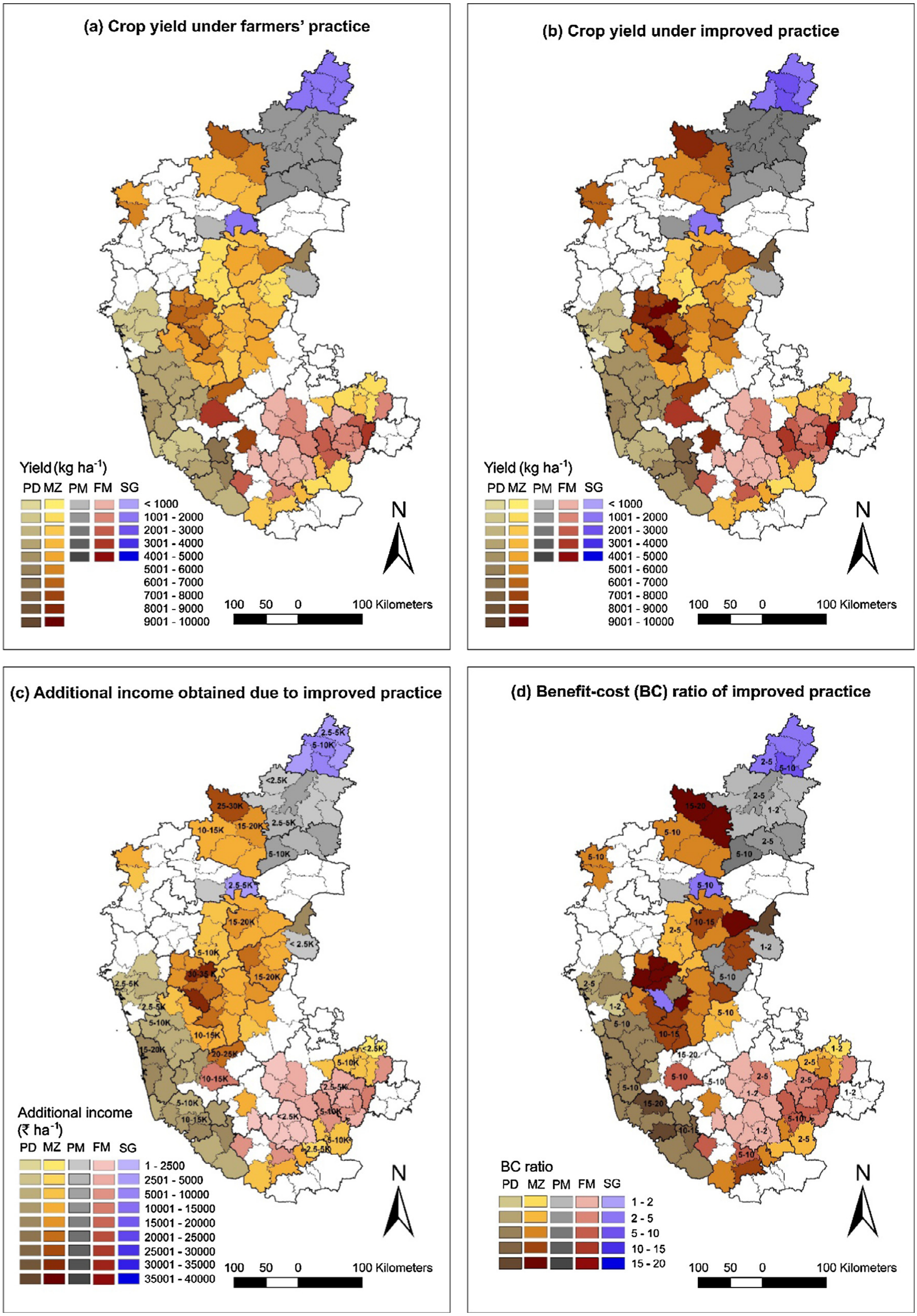

Figure 9. *Spatial variability in crop yields under (a) conventional farming practice and (b) improved practice (c) additional net income due to Bhoochetana program; and (d) additional benefit–cost ratio of selected cereals [rice (PD), maize (MZ), pearl millet (PM), finger millet (FM), and sorghum (SG)] across the taluks of Karnataka during 2012.*

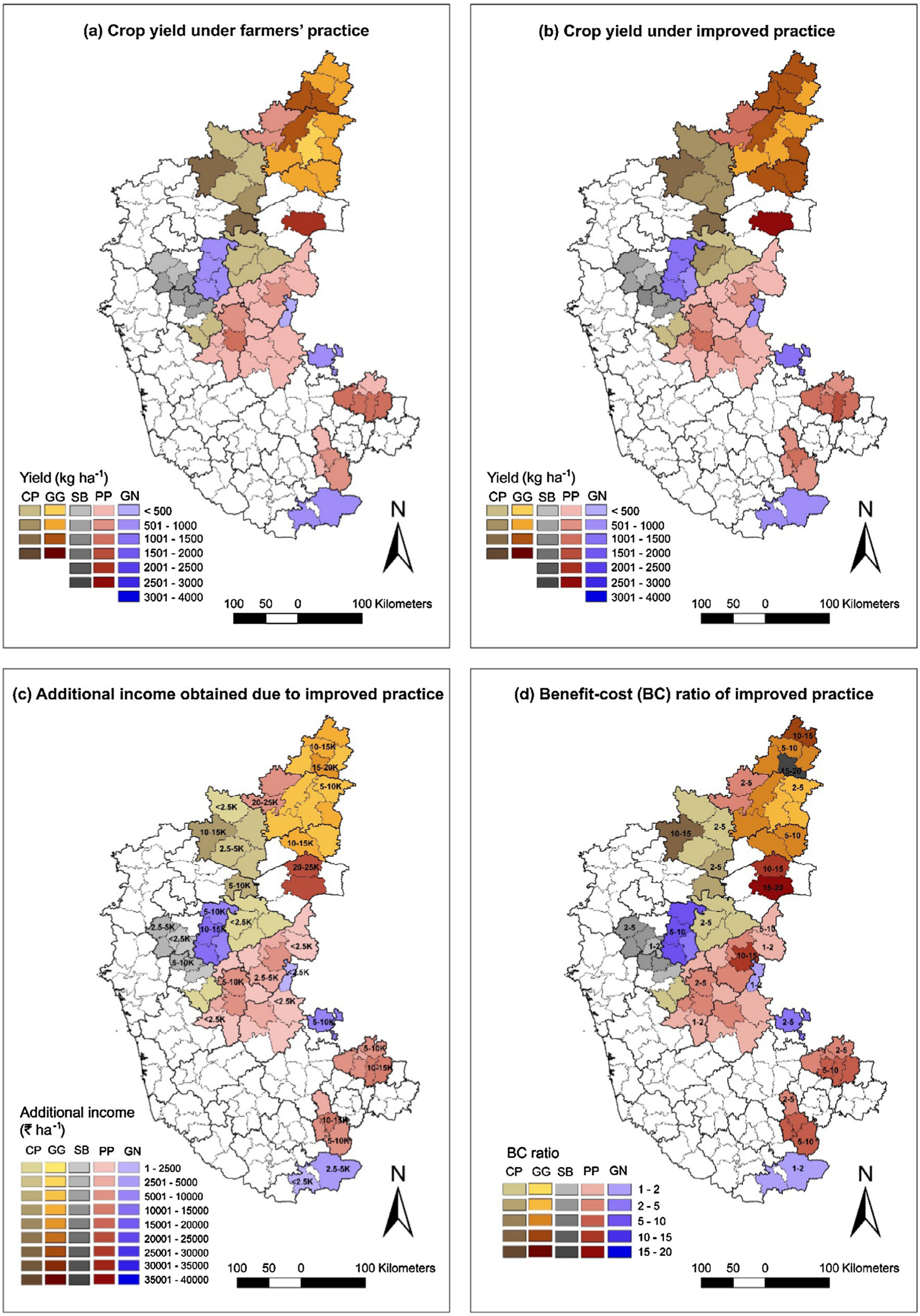

Figure 10. *Spatial variability in crop yields under (a) conventional farming practice and (b) improved practice (c) additional net income due to Bhoochetana program; and (d) additional benefit–cost ratio of selected legumes [(chickpea (CP), Green gram (GG), and pigeonpea (PP)] and oilseed crops [Soybean (SB) and groundnut (GN)] across the taluks of Karnataka during 201.*

Table 2. *Average crop yield, net income, and benefit–cost (BC) ratio of selected crops under improved practice (IP) and conventional farming practice (FP) with full cost in normal rainfall (2010), dry (2011), and very dry (2012) years in Karnataka*

Crop	No. of taluks	Mean rainfall (mm)	Yield ($kg\ ha^{-1}$)			Net income [a] ($Rs.\ ha^{-1}$)	BC ratio
			IP	FP	Increase (%)		
2010 (Normal year)							
Chickpea	13	759	1820	1350	34	9770	5.3
Mung bean	14	800	760	550	40	7970	4.4
Groundnut	18	572	1810	1300	40	11900	6.7
Maize	31	655	7250	5410	34	16220	9.1
Pearl Millet	8	685	2390	1710	40	6030	3.3
Pigeonpea	14	836	1630	1210	35	14670	7.9
Finger millet	22	624	2320	1700	36	5960	3.5
Sorghum	8	614	2410	1780	36	5710	3.1
Soybean	9	863	2650	2010	32	9250	5.1
Mean		**712**	**2560**	**1890**	**36**	**9720**	**5.4**
2011 (Dry year)							
Chickpea	32	407	1110	830	35	8030	4.4
Mung bean	18	484	830	580	41	9620	5.4
Groundnut	32	389	1900	1340	42	15210	9.0
Maize	55	470	5270	3950	33	12930	8.5
Rice	25	2720	5580	4480	25	12160	9.7
Pearl millet	12	415	2370	1710	38	6460	3.6
Pigeonpea	29	473	1230	890	38	12450	7.5
Finger millet	39	485	2040	1550	31	5100	3.8
Sorghum	13	451	3010	2150	40	8640	5.1
Soybean	11	520	1850	1320	41	9020	5.0
Mean		**681**	**2520**	**1880**	**36**	**9960**	**6.2**
2012 (Very dry year)							
Chickpea	33	382	780	600	30	5330	3.1
Mung bean	12	592	1090	820	33	11730	6.3
Groundnut	46	274	1030	780	33	9400	6.0
Maize	61	318	5080	3850	32	14450	9.2
Rice	50	1375	4770	3760	27	12950	8.9
Pearl millet	26	380	1980	1490	33	5750	3.4
Pigeonpea	42	367	1040	810	29	9030	5.2
Finger millet	45	283	1680	1260	33	6300	4.4
Sorghum	11	388	2510	1940	29	8650	4.7
Soybean	12	465	1570	1170	34	8980	5.1
Mean		**482**	**2150**	**1650**	**31**	**9260**	**5.6**

[a] Conversion rate: US$ 1 = Rs. 66.54 (September 29, 2016).

However, researchers managed to get trial data and modeling results showing large-yield potentials in rainfed regions, which could be harnessed through various land, water, and nutrient management practices (Singh *et al.*, 2009; Wani *et al.*, 2003, 2012a). *Bhoochetana*, thus, became one of the best scaling-up examples to demonstrate the science-led interventions like balanced fertilizer application along with improved cultivars and management practices that contributed to 30–35% of the additional yield. Complete adoption of science-led approaches may take the agricultural productivity level higher by two- to five fold. This approach may also address the issue of malnutrition with quality food grains as a large number of people in the developing countries are malnourished due to poor quality of the produce. Thus, with the application of micro and secondary nutrients, quality of food and fodder can also be improved to address the nutrition and health issues (Chander, Wani, Sahrawat, & Rajesh, 2015; Haileslassie *et al.*, 2013; Sahrawat *et al.*, 2010). The increase in crop yield and net income has made important contributions to household budgets in rural areas. The cumulative effect of integrated management approach on crop yield resulted in significant BC ratio for major crops in the state. The analysis revealed that cereal, oilseed, and legume crops have also performed better in terms of return on investment. The profit maximization proposition is high for cash crops due to their inherent commercial nature.

In the present study, it is observed that the rainfall variation in low rainfall years caused significant impacts on crop yields and as a result, the yield gain was reduced. However, crop yield was considerably higher when compared to FP indicating that even under moisture-stressed situations IP helped farmers (Uppal, Wani, Garg, & Alagarswamy, 2015). It shows that the use of micronutrients, new cultivars, and other improved practices have a greater impact on the crop yields. Similarly, legume and oilseed crops have also performed well throughout the project period. Since legumes form a major part of staple food crops in the state, efforts are needed to revive the cropping system with new knowledge, practices, methods, and approaches.

The economic returns for every dollar invested by the farmers ranged from 3 to 14. In 2011 and 2012, the combined gross value of increased agricultural production in the state was US $242 million, despite the fact that 2012 was a drought year with 26% of deficit rainfall in the state. The program benefited nearly 3.6 million farmers across 30 districts. The net income obtained by adopting the improved technologies varied from

Table 3. *Comparison of net returns for improved versus conventional farming practices reported since 2000 for different crops and management interventions in rainfed crop production in India*

Intervention	Crop	Net returns (US $/ha/season)		Increase (%)	Benefit–cost ratio		Reference
		Base	Improved		Base	Improved	
a. Tillage							
Tillage + fertilizer (Inceptisol) (9 years)	Pearl millet	207	254	23	1.93	2.33	Maruthi Sankar et al. (2012)
Tillage + fertilizer (Vertisol) (9 years)	Pearl millet	153	285	86	1.89	3.52	Maruthi Sankar et al. (2012)
Tillage + fertilizer (Aridisol) (9 years)	Pearl millet	44	86	95	1.12	1.26	Maruthi Sankar et al. (2012)
b. Rotations, fallows, intercropping							
Alley cropping	Soybean, safflower, tree products	117	156	33	1.88	2.27	Mutanal, Patil, Patil, Shahapurmath, and Maheshwarappa (2009)
Alley cropping, discounted @ 12%	Soybean, safflower, tree products	39	58	49	1.88	2.27	Mutanal et al. (2009)
Leucaena-based agroforestry	Cowpea, timber	145	542	274	1.86	3.17	Prasad et al. (2010)
Biomass retention, double cropping	Rice-vegetable sequences	84	752	795	0.46	1.82	Das, Patel, Munda, Hazarika, and Bordoloi (2008)
Crop mixtures, intercropping	Wheat, lentil, toria	101	437	333	1.79	2.1	Kumar, Prakash, Mina, Gopinath, and Srivastva (2008)
Intercropping	Maize, black gram	89	194	118	1.45	1.78	Sheoran, Sardana, Singh, and Bhushan (2010)
Intercropping	Pigeonpea, maize	123	346	181	2.61	2.75	Marer, Lingaraju, and Shashidhara (2007)
c. Fertilizers and soil amendments							
Phosphorus and biofertilizers	Pigeonpea	224	444	98	2.51	4.09	Singh and Yadav (2008)
Fertilizer + farm yard manure	Rice, niger	175	303	73	2.07	2.21	Gogoi, Barua, and Baruah (2010)
Fertilizer + organic inputs	Sesame	54	248	359	1.39	2.43	Deshmukh and Duhoon (2008)
Foliar spraying with calcium nitrate	Rice	194	327	69	0.86	1.38	Kundu and Sarkar (2009)
Foliar spraying with potassium chloride	Hybrid cotton	317	454	43	1.87	2.24	Aladakatti et al. (2011)
Phosphorus + vesicular arbuscular mycorrhiza	Wheat	159	268	68	1.55	1.86	Singh and Singh (2008)
d. Pest and disease control							
Improved weed control	Wheat	208	398	91	0.60	1.37	Singh, Singh, Singh, and Prasad (2010)
e. Improved varieties							
Improved versus local varieties in farmers' fields	Chickpea	196	360	84	4.28	5.6	Shiyani, Joshi, and Bantilan (2001)
Improved versus local varieties	Chickpea	142	199	40	1.34	1.58	Kiresur et al. (2010)
Improved versus local varieties (mean overall crops in farmers' fields)	Pearl millet, sorghum, mung bean, groundnut, wheat, barley, mustard and chickpea	208	283	36	2	2.58	Mann et al. (2009)

Source: modified from Harris and Alastair (2014)

Rs. 5,000 to Rs. 16,000 ha^{-1} depending on the crop, soil type, and rainfall condition. This is evident not only during the normal rainfall years but also during dry and very dry years, thereby indicating that improved crop management practices are crucial. The study on social impact assessment revealed that the additional income enabled farmers to reinvest in agriculture and agriculture-related infrastructures (40%) along with loan repayment (10%) and asset creations (13%). *Bhoochetana* program also enhanced the knowledge about agriculture among different stakeholders. Interestingly, the awareness about rainfed technologies enabled men and women to take decisions jointly in the program (ICRISAT, 2014). Thus, the *Bhoochetana* program not only bridged large yield gaps but also enhanced the social benefits among the participating farmers and contributed to their improved livelihoods.

The integrated approach often offers to minimize risks related to production, maximizes water-use efficiency, and minimizes production costs (Wani *et al.*, 2003, 2012a). In case of *Bhoochetana*, science-led innovative approaches were implemented to realize higher yield with modifications in soil, water, and crop managements. Such modifications in crop management often requires significant changes in the technological and economic support to the farmers, especially in the regions where farmers are not accustomed to using micronutrients to rejuvenate the soil and enhance the yield. Thus, the rainfed areas of semi-arid regions could be more favorable for adoption of such integrated approaches (*Bhoochetana*), because the farmers are more receptive toward new interventions and quickly become familiar with integrated technologies to enhance their crop yields.

This partnership program has explored new ways of extension system, which is unique in its composition and functioning. It is essential that the traditional extension systems are replaced with this model, where the research supports innovation at the local level. The important learning from this program was that support from research systems need to focus more on developing an interface with other sectors in order to achieve the desired growth in the agricultural sector. Mechanism governing the research system requires major attention as well as the ability and attitudes for engaging in partnerships. Attention should be given toward implementation of public awareness strategies through print and mass media, along with training and field exposure activities. Such changes are not necessarily expensive but have preconditions for effective investment in research and can contribute toward innovation. Similarly, extensive investments should create the capacity to identify new and promising alternatives at farm levels and ensure that they are supported in the right direction by engaging potential partners.

6. CONCLUSION

The preceding discussion revealed that the yield and economic benefits of *Bhoochetana* program contributed to improving the rural livelihoods in Karnataka. Soil fertility analysis, the entry point activity, evidently showed that soils were largely deficient not only in organic carbon but also in micro and secondary nutrients like Zn, B, and S. Thus, the taluk-level crop-specific fertilizer recommendations were made available. Balanced fertilizer applications both in rainfed and irrigated areas along with seed treatment and improved cultivars directly influenced the crop yield as IP recorded a yield of 2440 kg ha^{-1} compared to 1810 kg ha^{-1} in FP. Similarly, an average net income of Rs. 26,290 ha^{-1} estimated from FP and Rs. 35,540 ha^{-1} from IP indicated an additional 35% income by adoption of IP. There is a huge variability recorded in crop yields based on spatial and temporal scales for different crops. There is strong relationship between crop yield and rainfall received, irrespective of the different types of soils and management conditions. Despite high water scarcity in 2011 and 2012, IP helped farmers to harvest an additional 20–30% of yield; however, the net return was relatively less compared to the wet and normal rainfall years.

The improved practices demonstrated with farmers' participation increased the yield of cereals, legumes, and oilseeds. Improved crop management system resulted in higher income per ha than in the conventional farmers' practice. The integrated approach adopted with great willingness of consortium partners including the line departments helped in bridging large yield gaps that existed in the state. The net additional value generated by *Bhoochetana* has contributed significantly to the state's economy. The high return on investment suggests that there is a great hope for future investment in dryland agriculture by implementing such improved crop management practices. Crop production for food security and poverty alleviation in rainfed regions can be increased, when the smallholder farmers adopt improved crop management practices to increase their farm productivity and income. This is possible with the government interest in introducing science-led innovations to bridge the large yield gaps. However, it is not possible for smallholder farmers to increase their farm size with increased issues of land fragmentation. Thus, intensification is one of the viable options to enhance the efficiency of the land with improved knowledge and technologies. This proposition can be taken forward to address the land quality and food security issues together to build system resilience. Even though, the BC analysis at farm level indicates economic benefits, farmers may lack the opportunity to purchase agricultural inputs to undertake the sowing operations and thus lack the benefit. In this context, the incentive mechanism, practiced by the Government of Karnataka to smallholder farmers, is another option to promote the sustainable intensification of improved crop management practices in dryland agriculture.

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