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| Abstract | Legumes occupy a very important place in food systems for being the main source of protein for very large vegetarian population globally as such and an important component of sustainable agriculture because of their unique ability to fix atmospheric nitrogen biologically. However, productivity and production in legumes is quite low to commensurate with the current and future demands. Countries like India with a large population had to import 5–six million tons of legumes annually to meet local demand till recently. Low genetic potential of existing varieties with farmers and poor management practices result in low productivity of legumes. New science developments like development of hybrid technology in pigeon pea, marker-assisted breeding, as well as gene editing/splicing and genetic transformations have opened up new vistas for developing high-yielding and stress-tolerant legume cultivars. Most tropical soils where most legumes are grown are degraded, and widespread deficiencies of secondary and micronutrients are observed in Asia and Africa. In order to harness the best available potential of legumes to produce protein-rich food as well as build soil health, integrated system approach needs to be adopted and followed. Soil health mapping across various agro-ecologies and addressing the issues of seed supply systems along with efficient knowledge delivery systems are a must. Good results by adopting integrated system approach in India showed that farmers enhanced the productivity of legumes by 20–50% in crops like pigeon pea, chickpea, soybean, green gram, groundnut, and black gram. One rupee spent on soil test-based fertility management in integrated approach brought returns of Rs 3 to Rs 15. Replacement of existing pigeon pea and chickpea varieties used by farmers with high-yielding improved cultivars showed increased productivity by 30% to 120%. Mission projects like *Bhoochetana* covering 4.75 million ha in Karnataka and also in Andhra Pradesh have demonstrated the need for development research to overcome the *death valley* of impacts and ensure sustainable productivity by overcoming compartmental approach. A new paradigm in agricultural development research is needed to benefit the farmers through science-based interventions. |

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# Chapter 10
# Scaling Up Food Legume Production Through Genetic Gain and Improved Management

**Suhas P. Wani, Girish Chander, Mukund D. Patil, Gajanan Sawargavkar, and Sameer Kumar**

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## 10.1 Tropical Legumes: Major Food Crops and Current Status

Pulses are important part of cropping systems and food systems in Asia, Africa, and Latin America and occupy about 5.8% of the world's arable land area (Joshi and Parthasarathy Rao 2017). Pulses are unique largely due to their ability to grow on marginal soils as they are able to fix most of their nitrogen requirement through biological nitrogen fixation (BNF), are main source of proteins for vegetarian people, and are also able to withstand stress situations such as drought. In 2011–2013, pulses accounted for 80 million ha of global crop area and produced 72 million metric t of grain. With respect to production globally, dry beans account for 32%, chickpea 17%, dry peas 14.6%, cowpea 8.9%, lentils 7%, pigeon pea 6.2%, and broad bean 5.8%. During the years 2005–2007, total production was around 60 million metric t, and so there is a significant increase in production in Canada and Australia, the area expansion under pulses in Africa, and the export-oriented production in Myanmar (Parthasarathy Rao et al. 2010). Developing countries account for 70% of the global pulse production, but there is huge yield gap for pulses between developed (1640 kg ha$^{-1}$) and developing countries (765 kg ha$^{-1}$). The differences are apparently due to differences in inputs, technology, and infrastructure.

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In the semi-arid tropics, most legumes, in general, are grown in marginal lands under rain-fed conditions with minimal inputs, using seeds of low-yielding cultivars available with farmers. With increasing water scarcity and increased water demand for growing crops due to impacts of climate change, legumes would be main food crops to replace cereals grown currently. Legumes with low crop yields, to be grown with minimum inputs on marginal soils, largely by the small farm holders and poor market linkages resulted in these crops to be referred as neglected and underutilized species (NUS). In the search of climate-resilient agriculture, international bodies are promoting and popularizing climate-resilient/smart agriculture with smart crops. ICRISAT has termed the dryland legumes as smart crops as these are good for the farmers, good for the planet, and also good for the people (ICRISAT, 2017). However, to address the sustainable development goals (SDGs) particularly the SDG 2 of achieving zero hunger and SDG 3 of good health and wellbeing during the climate change era, there is an urgent need to diversify the food systems as well as promote locally grown nutrient-rich food crops which were NUS (Li et al. 2018). The Food and Agriculture Organization (FAO) along with several national and AU7 international partners has recommended Future Smart Food (FSF) concept to address the problems of climate change, food security, and malnutrition in Asia, and several food legumes have been prioritized by a number of countries for positive interventions using FSFs (Li and Siddique, 2018).

Large yield gaps up to fivefold between the current farmers' yield and the achievable potential yields for almost all the crops exist in Asia and Africa (Rockstrom et al. 2010; Wani et al. 2012b & c) largely due to existence of *death valley of impacts* as a large number of small farm holders are deprived of extension support about the new technologies as well as improved cultivars and inputs (Wani et al. 2012a and 2018b). Many technologies and improved cultivars don't see the light of the day on farmers' fields largely due to existence of lack of synergy among various actors involved in different phases from discovery to outcomes and impacts. Most of the actors including the scientists who develop the technologies and improved products work in compartments/silos, and integrated and holistic solutions are not provided to the farmers, and the technologies/products fall in the *death valley of impacts* (Wani et al. 2018b). For achieving the impact, the researchers must engage in action/development research to develop appropriate solutions together with resource users as well as various actors involved in the impact pathway (Wani et al. 2018b; Hagmann et al. 2002) (Fig. 10.1).

## 10.2 Enhancing Productivity of Dryland Legumes

As the current farmers' crop yields are lower by two- to fivefold that of achievable potential yields in rain-fed agriculture which are largely due to knowledge gap and not the technology gap, there is an urgent need to undertake development research for scaling up the impacts to bridge the yield gaps. However, it's a new branch of AU8 science, so to achieve the impacts, farmers look for the holistic and integrated

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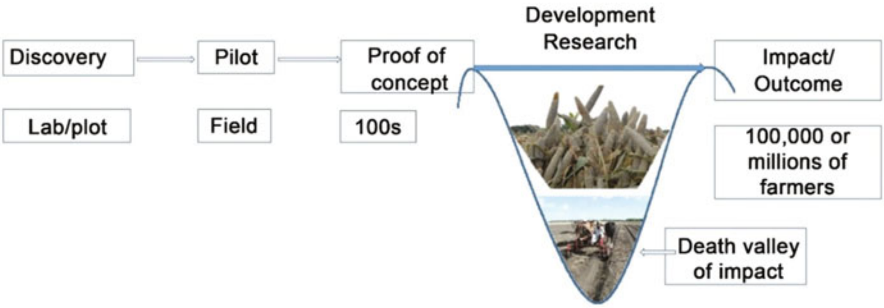


**Fig. 10.1** Death valley of impact (Source: Wani and Raju, 2016)

solutions in contrast to the compartmental solutions provided at present. This approach involves science-based solutions integrating backward and forward linkages using new technologies such as information and communications technology (ICT), artificial intelligence (AI), machine learning (ML), remote sensing (RS), crop and water budgeting simulations, market information, as well as inputs supply. Such a model needs partnerships with various sectors, and initial transaction costs are higher, but the impacts are far larger than expected (Wani et al., 2018). A consortium approach involving partnerships among technology/knowledge-generating institutions, knowledge sharing institutions, and public and private institutions along with government departments is found the most appropriate to benefit the farmers (Wani and Raju, 2016).

### *10.2.1 Integrated Watershed Management Model*

For upgrading rain-fed agriculture, a holistic integrated watershed/catchment-level management approach is the desired, preferred, and proven strategy for sustainable food production including legume production to meet growing food demand. This approach also addresses issues of water scarcity, land degradation, and minimizing the impacts of climate change (Wani et al. 2018a 2012b, c, 2014, Wani et al. 2002b). Inclusive market-oriented development (IMOD) approach in watershed management meets the multiple objectives of zero hunger, no poverty, good health and wellbeing of people, climate action, gender equality, and building partnerships contributing to several sustainable development goals (SDGs). In rain-fed agriculture major risk of water scarcity can be addressed through integrated watershed development model which also contributed to crop diversification and sustainable intensification and water and soil conservation along with improved crop cultivars and management. This approach/model is built on the principles of four ICEs, i.e., Innovative, Inclusive, Intensification, and Income (4Is); Consortium, Convergence, Collective action, and Capacity building (4Cs); and Equity, Economic gain, Empowerment, and Environment protection (4Es) (Wani et al. 2002, 2012a). This model was developed

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based on the comprehensive assessment (CA) of watershed programs in India undertaken by the ICRISAT-led consortium that revealed that 99% of watershed projects were economically remunerative and were silently revolutionizing rain-fed agriculture with a benefit-cost ratio of 2.14 while reducing runoff by 45% and soil loss by 2 to 5 tons/ha/y increasing agricultural productivity by 50% to 400% and cropping intensity by 35% (Joshi et al. 2008; Wani et al. 2008). However, large scope existed for improving the performance of 68% of the watershed projects as only 32% of the projects performed above average based on the detailed case study of 622 watershed projects implemented and published in India, which were performing below average. In addition, the changes due to impacts of climate change also need to be taken into account as the number of rainy days during the season has reduced and high-intensity rainfall events have increased (Rao et al. 2013) while choosing crops, cultivars, and drought-proofing measures.

#### 10.2.1.1 Water Management for Drought Proofing

Most important aspect in rain-fed agriculture is the efficient management of rainwater and other available resources in the watershed. The foremost intervention to be undertaken in any watershed development is efficient management of green water, i.e., soil moisture. Efforts must be to store as much rainwater in soil during the rainy season as possible by adopting in situ water and soil conservation measures such as contour planting, adoption of ridges and furrows/broad bed and furrows (BBF)/tied ridges/basins, conservation furrows, etc. Appropriate landform applications and [AU10] adoption minimize the risk of waterlogging and provide longer opportunity time for rainwater to infiltrate in Vertisols. Once the rainwater is stored in soil, the next step is to minimize unproductive evaporation losses of soil moisture and increase productive evapotranspiration (ET) producing crop growth by adopting measures like mulching with organic residues or plastic film, minimizing tillage, zero tillage, intercropping with appropriate crop, weeding, etc. Effectiveness of land and water management techniques is influenced by soil characteristics and climate. For example, heavy textured soils with clay content ranging from 40 to 60% or more have high water holding capacity, which makes Vertisols ideal soils for rain-fed/irrigated dryland agriculture. In India, one fourth of semi-arid region is covered by Vertisols. Infiltration rate when the soil is dry can be as high as 50–80 mm $h^{-1}$, through the [AU11] bypass/preferential flow through cracked Vertisols may be much higher. But after wetting, swelling of the soil closes the cracks leading to extremely low infiltration rates (less than 1 mm $h^{-1}$) (Pathak et al. 2013). Increased occurrence of heavy rainfall events with reduced frequency of low rainfall events is the characteristic impact of climate change in the SAT (Rao et al. 2013). The knowledge of soil characteristics and climate helps in selecting the appropriate land management practices.

Soil moisture availability is directly related to crop productivity generally in rain-fed agriculture except in case of heavy rainfall events in Vertisol areas where waterlogging could become an issue affecting crop productivity adversely. Extended

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dry spell during critical crop growth period significantly reduced crop yield, and supplemental irrigation using harvested rainwater significantly enhances crop productivity. Thus, avoiding waterlogging situation during high rainfall event and conserving soil moisture during the dry spell are essentials for any crop to avoid yield loss. The proper withdrawal of excess water through furrow and increased storage of soil moisture in broad bed by providing more opportunity time for rainwater infiltration take care of waterlogging due to excess rainfall and water scarcity due to extended dry spells, respectively.

Furrows made at a specified gradient (0.2 to 0.4%) carry runoff water into waterways slowly and then releasing in the waterways to carry along the slope in the farm pond. Runoff from entire field may be captured by constructing water harvesting structures. Long-term micro-watershed experiments at International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India, showed that implementation of soil and water conservation practices during 1976 to 2012, intercropping/sequential cropping, and integrated nutrient management produced average crop yield of 5.1 t $ha^{-1}$ $y^{-1}$ (sorghum/pigeon pea intercropping) compared to 1.1 t $ha^{-1}$ $y^{-1}$ (sole sorghum) with farmer's practice (Wani et al. 2011). Much emphasis must be given to rainwater management and harvesting at farm level as a drought-proofing strategy in the drylands (Wani et al. 2002b). Pilot studies in drylands of Andhra Pradesh, Telangana, Maharashtra, and other sites indicated that small low-cost farm ponds provide access to water for critical irrigation during drought and check yield losses up to 20–60% (Chander et al. 2018).

Conservation agriculture (CA) is another important in situ intervention considered for practicing resilient and climate-smart agriculture. The basic components of CA are (1) zero or minimum tillage; (2) retention of crop residues on the soil surface; and (3) crop diversification. Minimal tillage reduces quantity and velocity of surface runoff and reduces soil erosion and nutrient loss; incorporation of crop residue enhances soil moisture availability and reduces evaporation losses (Jat et al. 2012, 2015; Araya et al. 2012; Araya et al. 2011; Potter et al. 1995; Gilley et al. 1986; Massee and Cary, 1978), improves the infiltration by restricting surface runoff (Yule et al. 1990), and reduces surface sealing from raindrop impact (Potter et al. 1995). Crop diversification reduces risk of the crop failures and is recognized as a cost-effective solution to build resilience into agricultural production system (Rusinamhodzi et al. 2012; Lin, 2011). Diversification brings stability in soil fertility through cultivating legumes with cereals in rotation or with intercropping system (Myaka et al. 2006; Aslam et al. 2003; Chamango, 2001). Recent studies have reported that CA improved crop productivity by 20–120% and water use efficiency by 10 to 40% (Ngwira et al. 2012; Rockstrom et al. 2009; Ito et al. 2007; Li et al. 2007; Wang et al. 2007). But adoption rate of CA among the farmers is constrained by economic conditions of small and marginal farmers as well as lack of appropriate machinery. Also, the increased crop yields are not evident in initial years although CA reduced runoff and soil loss in long-term experiment at ICRISAT (Jat et al. 2015). In the SAT regions, crop residues are primarily used for animal feeding and fetch high value, plus after harvest fields are open for common grazing; also as a result farmers are hesitant to adopt crop residue retention in field. Moreover, yield

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advantage of CA over farmers' practices is not much clear. Some of the studies reported no improvement or negative effects on crop yield by adopting such techniques (Baudron et al. 2012; Van den Putte et al. 2010).

#### 10.2.1.2 Soil Health Mapping and Balanced Nutrients Application

Soil health is a critical factor in crop production, but unfortunately farmers are not aware about their soil health. Even though knowledge about soil analyses is available with the scientists, farmers apply blindly NPK fertilizers only as advised by the fertilizer dealers/neighbors resulting in imbalanced use of nutrients and low crop yields with increased cost of cultivation (Wani et al. 2017). Healthy soils are a must for good crop production and healthy foods which are must for healthy people. When the world is facing severe problem of malnourished people, legumes grown on healthy soils could contribute significantly to meeting SDG 2. However, analysis of farmers' fields across different states in India as well as in China, Thailand, and Vietnam as well as in Africa showed widespread deficiencies of multiple nutrients including secondary and micro- along with macronutrients. In India across the states, widespread deficiencies of essential nutrients including secondary and micronutrients along with the primary nutrients were recorded which were found to be directly associated with low crop yields in farmers' fields (Table 10.1; Wani et al.2018b, 2017, 2016,2015a,b, 2013, 2012a, 2011; Sahrawat et al. 2016, 2007; Rego et al. 2005; Rao et al. 2014; Chander et al.2018b, 2016, 2014, 2013a,b, 2012).

Response studies to balanced nutrients in on-farm trials have recorded significant productivity benefits varying between 20 and 50% in crops like pigeon pea, chickpea, green gram, and black gram (Tables 10.2, 10.3, 10.4 and 10.5; Fig. 10.2).

### *10.2.2 Improved Cultivars with High Genetic Gain*

Genetic gain is the amount of increase in performance mainly yield that is achieved annually through artificial selection (Xu et al. 2017) which results in development of stress-tolerant improved cultivars. Defined as the rate of increase in yield over a given period, the real genetic gain is estimated against potential yield but can also be assessed under defined stress conditions. Genetic gain in legumes, like other crops, is mostly based on pedigree and performance-based selection over the past half-century. Monotonous breeding with the less appreciated interdisciplinary approach, resulting in inefficient selection criteria and extended breeding cycles, failed to unlock stagnant genetic gains in legumes. Faster genetic gains in legumes could be achieved through multidisciplinary approach where breeders, molecular biologists, physiologists, plant nutritionist, plant protection scientists, and data scientists work together. The integration of modern genomics, high-throughput phenomics, simulation modeling, crop improvement, and appropriate agronomy enhances genetic gains. Selection intensity, generation interval, and improved operational efficiencies

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t1.1 **Table 10.1** Percentage of deficient farmers' fields supplying inadequate levels of available nutrients across various states in India

| | State | District | Mandal/taluk/block | % samples deficient in soil org C | % fields deficient in plant nutrients | | | | | | | | | | No. of samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| t1.2 t1.3 | | | | | P | K | S | Ca | Mg | Zn | B | Fe | Cu | Mn | |
| t1.4 AU16 AU17 | Andhra Pradesh | All 13 districts | Kollur, Sattenapalli, Kanigiri, Konakana Mitta, Ongole, Indukurpeta, Podalakur, TP Gudur, Konduru, Ghantasala, Akividu, Kamavarapu Kota, Gangavaram, Yeleswaram, Penukonda, Raptadu, Kothacheruvu, Santhipuram, V Kota, Porumamilla, B Mattam, Veeraballe, Sambepalle, Banaganapalli, Devanakonda, Parvathipuram, Pusapatirega, Polaki, Ranasthalam, Seethampeta, Butchayyapeta, Chintapalle, Padmanabham | 58 | 23 | 06 | 47 | 29 | 03 | 52 | 32 | 02 | 05 | 01 | 5319 |
| t1.5 | Karnataka | Bengaluru, Bidar, Bijapur, Chamrajnagar, Chikballapur, Chitradurga, Davangere, Dharwad, Gadag, Gulbarga, Hassan, Haveri, Kolar, Raichur, Tumkur, Yadgir | All taluks in 16 districts | 52 | 41 | 23 | 52 | – | – | 55 | 62 | – | – | – | 92,864 |
| t1.6 | Telangana | Medak | Patancheru | 59 | 10 | – | 35 | 01 | 0 | 62 | 19 | 01 | 0 | 0 | 189 |

(continued)

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t1.7 **Table 10.1** (continued)

| | | | | % samples deficient in soil org C | % fields deficient in plant nutrients | | | | | | | | | | No. of samples |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| t1.8 t1.9 | State | District | Mandal/taluk/block | | P | K | S | Ca | Mg | Zn | B | Fe | Cu | Mn | |
| t1.10 | Maharashtra | Satara | Khandala | 52 | 26 | 03 | 80 | – | 0 | 76 | 67 | 05 | 0 | 0 | 324 |
| t1.11 | Karnataka | Bellary | Sandur | 35 | 30 | – | 55 | – | – | 67 | 23 | 15 | 08 | 0 | 879 |
| t1.12 | Maharashtra | Palghar | Jawhar | 05 | 43 | 03 | 57 | – | 0 | 27 | 57 | – | 0 | 0 | 95 |
| t1.13 | Telangana | Mahabubnagar | Wanaparthy | 81 | 46 | 14 | 83 | 38 | 01 | 81 | 73 | 10 | 0 | 39 | 192 |
| t1.14 | Andhra Pradesh | Anantapur | Penukonda | 87 | 69 | 15 | 77 | 29 | 0 | 94 | 77 | 07 | 0 | 44 | 190 |
| t1.15 | Andhra Pradesh | Kurnool | Bethamcherla | 50 | 15 | 08 | 76 | 80 | 0 | 75 | 35 | 04 | 0 | 12 | 169 |
| t1.16 | Karnataka | Bijapur | Basavan Bagewadi | 49 | 89 | – | 71 | – | 0 | 94 | 16 | 08 | 0 | 0 | 187 |
| t1.17 | Telangana | Medak | Pulkal, Sangareddy | 71 | 28 | 06 | 55 | 06 | 0 | 66 | 45 | – | 0 | 02 | 246 |
| t1.18 | Rajasthan | Alwar, Banswara, Bhilwara, Bundi, Dungarpur, Jhalawar, Sawai Madhopur, Tonk, Udaipur | Rajgarh, Kushalgarh, Jahajapur, Hindoli, Bichiwara, Jhalarapatal, Khandar, Deoli, Newai, Girwa | 38 | 45 | 15 | 71 | – | – | 46 | 56 | – | – | – | 422 |
| t1.19 | Jharkhand | Gumla, Kharsawan | Raidih, Saraikala | 42 | 65 | 50 | 77 | – | – | 71 | 97 | – | – | – | 115 |
| AU18 t1.20 | Madhya Pradesh | Barwani, Dewas, Guna, Indore, Raisen, Rajgarh, Sagar, Sehore, Shajapur, Vidisha, Jhabua, Mandla | Barwani, Devas, Madusudangarh, Samer, Silwani, Rajgarh, JC Nagar, Sehore, Agar, Vidisha, Lateri, Meghnagar, Niwas | 22 | 74 | 01 | 64 | – | – | 66 | 79 | – | – | – | 341 |
| t1.21 | Odisha | Mayurbhanj, Keonjhar | Mayurbhanj, Harichandanpur | 18 | 73 | 10 | 96 | – | – | 07 | 99 | – | – | – | 177 |

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**Table 10.2** Effects of soil test-based application of micronutrients and secondary nutrients in pigeon pea crop in Karnataka

| District | Crop | Year | Grain yield kg $ha^{-1}$ | | % increase over FP |
|---|---|---|---|---|---|
| | | | Farmers' practice (FP) | Balanced fertilization | |
| Bagalkot | Pigeon pea | 2011 | 1080 | 1440 | 33 |
| Bellary | Pigeon pea | 2011 | 620 | 920 | 48 |
| | | 2012 | 310 | 460 | 48 |
| Bidar | Pigeon pea | 2010 | 1230 | 1700 | 38 |
| | | 2011 | 790 | 1030 | 30 |
| Bijapur | Pigeon pea | 2010 | 920 | 1160 | 26 |
| | | 2011 | 740 | 980 | 32 |
| Davanagere | Pigeon pea | 2011 | 470 | 560 | 19 |
| | | 2012 | 530 | 670 | 26 |
| Gulbarga | Pigeon pea | 2010 | 1380 | 1870 | 36 |
| | | 2011 | 1240 | 1850 | 49 |
| Kolar | Pigeon pea | 2011 | 1360 | 1850 | 36 |
| Raichur | Pigeon pea | 2010 | 960 | 1280 | 33 |
| Ramanagra | Pigeon pea | 2011 | 1010 | 1430 | 42 |
| | | 2012 | 650 | 860 | 32 |
| Yadgir | Pigeon pea | 2010 | 1630 | 2230 | 37 |
| | | 2011 | 660 | 850 | 29 |
| | | 2012 | 1580 | 1960 | 24 |

in breeding are too expected to elevate the genetic gain. Improved seed access to farmers, combined with appropriate agronomic packages in farmers' fields, will deliver higher genetic gains. Enhanced genetic gains, including not only productivity but also nutritional and market traits, will increase the profitability of farming and the availability of affordable, nutritious food, especially in developing countries (Varshney et al. 2018). Once the improved cultivars are released, the next and most important step is to popularize the improved cultivars on farmers' fields.

#### 10.2.2.1 Development of Improved Cultivars

As indicated earlier conventional breeding alone cannot enhance the genetic gain and integrated breeding for higher and faster genetic gain through multidisciplinary team is essential. Worldwide legumes constitute 16% of a large number (5.55 million) of plant accessions assembled (FAO, 1996; Upadhyaya, et al. 2007). First and foremost, the need is to broaden genetic diversity using large germplasm collection (20,602 accessions of chickpea and 13,771 in pigeon pea), and it's a challenging task. The concept of core/mini core collection of the germplasm lines for

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t3.1 **Table 10.3** Effects of soil test-based application of micronutrients and secondary nutrients in chickpea crop in Karnataka

| | District | Crop | Year | Grain yield kg $ha^{-1}$ | | % increase over FP |
|---|---|---|---|---|---|---|
| t3.2 t3.3 | | | | Farmers' practice (FP) | Balanced fertilization | |
| t3.4 | Bagalkot | Chickpea | 2011 | 1550 | 2010 | 30 |
| t3.5 | Bellary | Chickpea | 2011 | 450 | 620 | 38 |
| t3.6 | Bidar | Chickpea | 2010 | 1660 | 2310 | 39 |
| t3.7 | Bijapur | Chickpea | 2010 | 1200 | 1560 | 30 |
| t3.8 | | | 2011 | 1200 | 1560 | 30 |
| t3.9 | Chitradurga | Chickpea | 2009 | 1240 | 1520 | 23 |
| t3.10 | Davanagere | Chickpea | 2010 | 1400 | 1780 | 27 |
| t3.11 | | | 2011 | 1300 | 1590 | 22 |
| t3.12 | Dharwad | Chickpea | 2009 | 1070 | 1430 | 34 |
| t3.13 | Gadag | Chickpea | 2011 | 710 | 1100 | 55 |
| t3.14 | Gulbarga | Chickpea | 2011 | 1040 | 1440 | 38 |
| t3.15 | Haveri | Chickpea | 2011 | 400 | 540 | 35 |
| t3.16 | Raichur | Chickpea | 2010 | 1340 | 1700 | 27 |
| t3.17 | Yadgir | Chickpea | 2011 | 560 | 750 | 34 |

t4.1 **Table 10.4** Effects of soil test-based application of micronutrients and secondary nutrients in green gram crop in Karnataka

| | District | Year | Grain yield kg $ha^{-1}$ | | % increase over FP |
|---|---|---|---|---|---|
| t4.2 t4.3 | | | Farmers' practice (FP) | Balanced fertilization | |
| t4.4 | Bidar | 2010 | 870 | 1200 | 38 |
| t4.5 | | 2011 | 810 | 1120 | 38 |
| t4.6 | | 2012 | 890 | 1190 | 34 |
| t4.7 | Bijapur | 2010 | 330 | 480 | 45 |
| t4.8 | | 2011 | 240 | 300 | 25 |
| t4.9 | Dharwad | 2011 | 950 | 1380 | 45 |
| t4.10 | Gadag | 2010 | 280 | 440 | 57 |
| t4.11 | | 2011 | 760 | 1080 | 42 |
| t4.12 | Gulbarga | 2010 | 460 | 590 | 28 |
| t4.13 | | 2011 | 480 | 690 | 44 |
| t4.14 | Yadgir | 2010 | 540 | 710 | 31 |
| t4.15 | | 2011 | 570 | 810 | 42 |
| t4.16 | | 2012 | 850 | 1100 | 29 |

t5.1 **Table 10.5** Effects of soil test-based application of micronutrients and secondary nutrients in black gram crop in Karnataka

| | District | Year | Grain yield kg $ha^{-1}$ | | % increase over FP |
|---|---|---|---|---|---|
| t5.2 t5.3 | | | Farmers' practice (FP) | Balanced fertilization | |
| t5.4 | Bidar | 2010 | 930 | 1260 | 35 |
| t5.5 | Gulbarga | 2011 | 410 | 560 | 37 |

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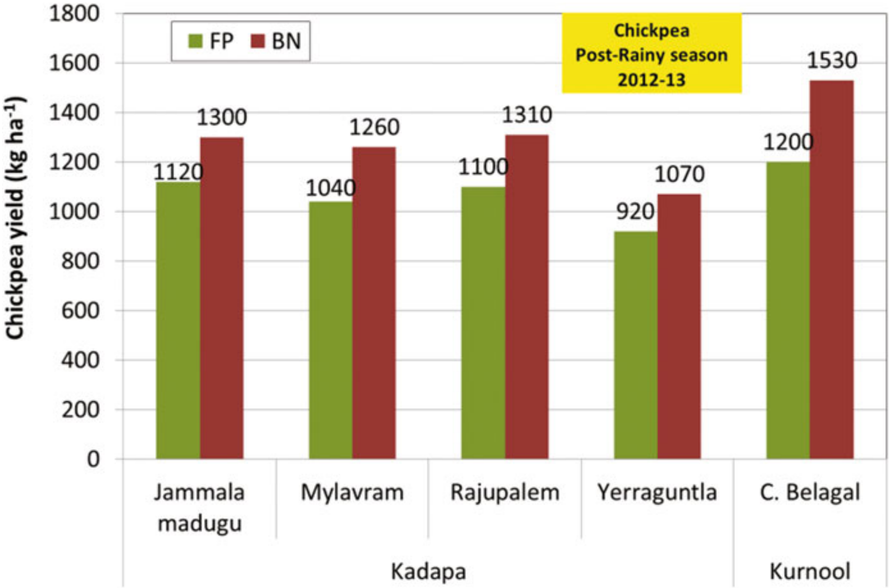


**Fig. 10.2** Productivity benefits in chickpea with balanced nutrition under Bhoochetana, Andhra Pradesh, during post-rainy season 2012

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effective utilization in breeding program is proposed (Frankel, 1984, Upadhyaya et al., 2006, 2016).

Pre-breeding is one of the potential genetic diversity-enhancing approaches. AU22 Introgression of desired genes from rich wild/exotic species to current-day cultivars is today's necessity for broadening the genetic base of legumes (Kumar et al. 2003).

Selection intensity and satisfactory heritability are an outcome of a robust breed- AU23 ing profile which can be further improved through field phenotyping or application of molecular markers, shuttle breeding, and multilocation testing/selection at national and international sites. A success story of pigeon pea hybrid has set an example where partnership between ICAR and ICRISAT resulted in release of world's first commercial pigeon pea hybrid ICPH 2671 in Madhya Pradesh (Saxena et al. 2018a).

Genomic approaches play important and critical role in enhancing the genetic gain process. Unraveling the genome sequence of soybean (1115 Mb), pigeon pea (833.07 Mb), chickpea (738 Mb), common bean (587 Mb), mung bean (548 Mb), adzuki bean (612 Mb), and cowpea (323 Mb) was done using high-throughput genotyping platform. This has generated sufficient genomic resources with associated phenotypic data to discover target traits and breeding of superior varieties (Varshney et al. 2018). Diversity array technology (DArT)-seq, restriction site-associated DNA sequencing, and high-throughput SNP approaches are used for developing high-density genetic maps, refining the QTL mapping, and identifying trait-linked markers in legumes in affordable costs in chickpea, pigeon pea, and soybean (Varshney et al. 2018). Marker-assisted selection (MAS), marker-assisted backcrossing (MABC), and marker-assisted recurrent selection (MARS) are used to breed climate-resilient legume crops (Varshney et al., 2018). AU24 LeasyScan phenotyping platform at ICRISAT; semi-hydroponic phenotyping system, Australia; GLO-Roots, USA; and X-ray computed tomography, UK, are few high-throughput phenotyping platforms used in crop improvement. Integration of modern phenotyping tools in breeding programs accelerates wider adaptability, resilience, increased productivity, and quantum jump in genetic gains (Varshney et al. 2018).

#### 10.2.2.2 Farmer Participatory Evaluation of Improved Cultivars

Balancing productivity, profitability, and environmental health is a key challenge for today's agriculture for ensuring long-term sustainability (Foley et al. 2011; Robertson and Swinton, 2005). However, most crop production systems in the world are characterized by low species and management diversity, high use of fossil energy and agrichemicals, and large negative impacts on the environment. Therefore, there is urgent need to focus our attention toward the development of crop production systems with improved resource use efficiencies and more benign effects on the environment (Foley et al. 2011; Tilman et al. 2002). Cropping system design provides an excellent framework for developing and applying integrated approaches to management because it allows for new and creative ways of meeting the challenge of sustaining the agricultural productivity.

The participatory varietal evaluation program on different varieties of legume crops was started by ICRISAT, along with NARS partners, toward increasing farmer productivity by facilitating the delivery of drought-tolerant, high-yielding, profitable variety of groundnut which is well adapted to a wide range of soil types, environments, and farming systems in different parts of India. The suitability of this variety was assessed by providing accredited, unbiased information to farmers on better adapted different crop varieties, or new and better cultivars of legumes, at the earliest opportunity. Secondly, this farmers' participatory varietal evaluation program with AU25 legume cultivars was conducted with an objective to initiate the process to scale up the adoption of suitable cultivars, having suitable traits for better adaptation to biotic and abiotic stresses to enhance or sustain productivity, and further scale up the spread of these varieties to satellite villages/taluks/districts.

The layout of this demonstration comprised of approximately half to 1 acre of farmers' field with adjoining field as control with his/her traditional variety. Similarly, emphasis was given on best-bet management practices comprising appli- AU26 cation of balanced nutrition, viz., 50 kg DAP, 10 kg borax, 50 kg zinc sulfate, and 200 kg gypsum $ha^{-1}$, and also other management practices, viz., weed and pest control. With these trials, farmers were exposed to benefits of improved legume varieties grown in their area and had the option of evaluating the performance of legume cultivar crop more or less in the same climatic and soil conditions with different levels of input management. Participatory. AU27

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The layout of varietal trial was designed to assess the performance of local legume variety with traditional way of input management (FP) and improved cultivar + best-bet inputs (IP) as shown in Layout 1. AU28

| Layout 1. Participatory varietal selection cum yield maximization trial with legume variety | |
|---|---|
| Traditional/local cultivars + farmers' inputs (FP) | HY cultivar + best-bet management (IP) |

The activity is promoted through ICRISAT's project which is being supported by different state governments in India with the active involvement of state agriculture departments. The program collects and delivers the data which not only assist farmers with the best choice of suitable variety available but also facilitate the registration and commercialization of this variety by plant breeders. The experimental protocol has been established to evaluate the performance of improved varieties/cultivars under balanced nutrition against a common set of traditional varieties of legumes to characterize their yield, quality, disease resistances/tolerances, and agronomic characteristics. The information on yield performance of both the practices, viz., improved practice and farmer's practice, are collected through crop cutting experiments by ICRISAT staff, FFs, and agriculture department staff/officials.

Details of Evaluation of Legume Cultivars in Karnataka During 2012 to 2016

Field trials for improved legume crop cultivars were evaluated in Karnataka during 2012 to 2016–2017, and details are presented in Table 10.6. The efforts were made to make available climate-smart crop cultivars which are tolerant of mid-season and end-of-season drought, and are high yielding were made available to farmers for their evaluation. The results revealed that there has been 12 to 24 percent increase in the legumes' productivity compared to local popular cultivar (Fig. 10.3). AU29

## 10.3 Agronomic Innovations for Enhancing Productivity and Production

Greater efforts are needed to popularize the best agronomic management practices among the farmers to improve the productivity and profitability of rain-fed system. Therefore, emphasis should be given on popularization of the climate-smart legume crops, to support farmer seed-sharing networks to ensure availability of diverse crop varieties and to encourage a diverse farming economy at landscape (if not always farm) level.

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t6.1 **Table 10.6** List of crop cultivars demonstrated in farmer's fields in different districts of Karnataka

| | District name | Pigeon pea | Green gram | Groundnut | Soybean | Groundnut | Cluster bean | Chickpea |
|---|---|---|---|---|---|---|---|---|
| t6.3 | Belgaum | ICPL87119 (Asha), hybrid (Puskal) ICPH2671 | SML 668 | ICGV 91114 | JS 9560, JS 335, DSB 21 | | HG 563 | JG 11, JAKI 9218 |
| t6.4 | Davanagere | Lakshmi (ICPL85063), Asha (ICPL871119), ICPH 2740, Puskal (ICPH2671) | – | ICGV 91114 | | | – | JG 11, JAKI 9218, ICCC 37 |
| t6.5 | Haveri | Asha (ICPL87119), Lakshmi (ICPL85063), Puskal (ICPH2671), ICPH 2740 | – | – | | | – | ICCC 37, JG 11, JAKI 9218 |
| t6.6 | Bijapur | Asha (ICPL87119), Lakshmi (ICPL85063) | SML668 | – | | | HG 563 | KAK 2, ICCC 37, JG 11JAKI 9218 |
| AU30 t6.7 | Chikmagalur | Lakshmi (ICPL85063), Asha (ICPL87119), Puskal (ICPH2671), ICPH 2740 | SML 668 | – | | | HG 563 | ICCC 37, JG 11, JAKI 9218 |
| AU31 t6.8 | Chamarajanagar | Lakshmi (ICPL85063), Puskal (ICPH2671) | SML 668 | – | | | HG 563 | KAK 2, ICCC 37, JG 11JAKI 9218 |
| t6.9 | Gadag | Lakshmi (ICPL85063), Puskal (ICPH2671), Asha (ICPL87119) | – | ICGV 91114 | | | – | JG 11, JAKI 9218 |
| t6.10 | Bangalore 2 | Laxmi (ICPL85063), Asha (ICPL87119), Puskal (ICPH2671) | – | – | | | – | |
| t6.11 | Tumkur | Lakshmi (ICPL85063) | – | ICGV 91114, ICGV 02266, ICGV 00308, ICGV 00351 | | ICGV 91114 | HG 563 | JG 11, JAKI 9218 |
| t6.12 | Chitradurga | | – | ICGV 91114 | | | HG 563 | JG 11, JAKI 9218 |

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| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Laxmi (ICPL85063), Asha (ICPL87119), Puskal (ICPH2671), ICPH 2740 | | | | | | |
| t6.13 | Yadgir | Puskal (ICPH2671), Asha (ICPL87119), Laxmi (ICPL85063) | – | – | | ICGV 91114 | – | JG 11, JAKI 9218 |
| t6.14 | Gulbarga | Puskal (ICPH2671), Asha (ICPL87119), Laxmi (ICPL85063), ICPH 2740 | SML 668 | – | | ICGV 91114 | HG 563 | JG 11, JAKI 9218 |
| t6.15 | Bidar | Puskal (ICPH2671), Asha (ICPL87119), Laxmi (ICPL85063), ICPH 2740 | SML 668 | – | JS 9560, JS 335, DSB 21 | | HG 563, N 87, RGE-986 | JG 11, JAKI 9218 |
| t6.16 | Bellary | Puskal (ICPH2671), Asha (ICPL87119), Laxmi (ICPL85063), ICPH 2740 | SML 668 | ICGV 91114 | | | HG 563 | JG 11, JAKI 9218, KAK 2 |
| t6.17 | Raichur | Puskal (ICPH2671), Asha (ICPL87119), Laxmi (ICPL85063), ICPH 2740 | SML 668 | ICGV 91114,ICGV 02266,ICGV 00308, ICGV 00351 | | | HG 563 | JG 11, JAKI 9218, KAK 2 |

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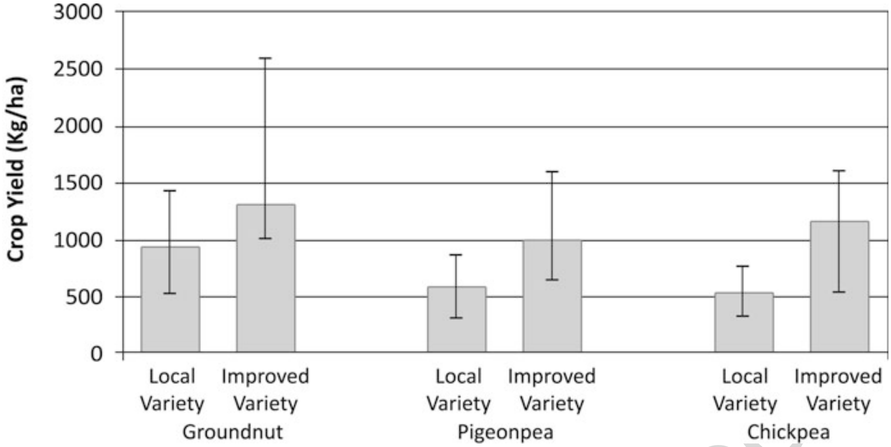


**Fig. 10.3** Comparison of grain yield of legumes under farmer participatory varietal evaluation

### *10.3.1 Cropping Systems Management and Length of Growing Period (LGP)*

Choice of the crops grown under rain-fed conditions should be made based on length of the adequate moisture availability during the crop-growing season. The length of the growing period (LGP) varies as per the soil type, rainfall pattern, and temperature. Based on the soil moisture holding capacity soils like Vertisols which can hold AU32 200 to 250 mm soil water, post-rainy season crops also could be grown even with 700 to 800 mm annual rainfall.

In sub-humid areas like Odisha, where humid period is more than 12 weeks' duration and the rainfall is twice that of PET, rice-based cropping systems are suitable, as other crops cannot tolerate water stagnation. Choice of post-rainy season crops is related to the moisture regime that plays a major role. In medium-deep AU33 Alfisols which provide greater potential for sole paddy cropping during rainy season with the cultivars of 120 to 130 days' duration. Similarly, in upland areas of Odisha, intercropping with short- to medium-duration crops, viz., pigeon pea, is best suited to make better use of soil water availability.

### *10.3.2 Land Resources Inventory for Selection of Legumes-Based Cropping System*

The land resources inventory (LRI) helps for the classification and mapping of soil characteristics from the LRI database. The LRI contains several attributes describing physical, chemical, and biological soil characteristics and other database. The database can be used to list the cropping pattern details within each of the

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physiographic sub-zones of the country. Details include the approximate planting and harvesting dates for each crop, the inundation land type on which it is grown, and whether the crop is irrigated. The system can be used to include a component that permits the evaluation of crop suitability. First, individual crop suitability ratings need to be analyzed, and then suitability for various cropping patterns is rated using a database of known and potential cropping patterns (rotations). This suitability modeling takes into account individual crop characteristics, input/management levels, soil physical characteristics, hydrologic and climatic conditions, and seasonal variability. Extrapolations of existing cropping system technologies can also be made to delineate suitable areas on a national scale.

### *10.3.3 Selection of Cropping Systems*

Depending on the normal rainfall and type of soil, crops and the cropping systems are generally evolved over the years by farming communities in an agro-ecoregion. Other considerations that determine the choice of cropping systems include food and fodder requirements, commodity markets, crop rotational requirements, and endemic pests and diseases affecting productivity. Depending on the possible length of growing season as estimated from seasonal rainfall, potential evapotranspiration, and soil characteristics, a double cropping system either a sequential system or an intercrop system could be adopted to enhance crop intensity and annual productivity (Table 10.7). While selecting sequential systems, duration of each crop and suitability of sowing windows in each cropping season are more critical. Sequential system requires short-duration crops/cultivars to fit into possible crop-growing season and to improve productivity.

In areas receiving >1000 mm rainfall and 30 weeks of effective growing season, only paddy-based cropping system is possible in red soils, shallow black soils, deep Aridisols, and Entisols. In deep black soils (Vertisols), sequential post-rainy season

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**Table 10.7** Information on crop critical stages, water requirement, and sensitivity to weather anomalies of important legume crops

| Crop | Critical growth stages | Water requirement (mm) | Duration (days) | Crop sensitivity |
|---|---|---|---|---|
| Pigeon pea | Emergence, flowering, pod formation, pod development | 500–800 | 140–180 | Frost-germination |
| Green gram/ black gram | Flowering, pod formation, pod development | 350–400 | 65–80 | Frost |
| Groundnut | Emergence, flowering, pegging, pod development | 500–700 | 90–140 | Frost-germination |
| Chickpea | Emergence, flowering, pod development | 300–500 | 85–130 | Frost-flowering |

Source: FAO irrigation and drainage paper 33, 56 crops, viz., chickpea/black gram/maize/green gram, are possible. Intercropping is possible in regions having 20–30 weeks of effective growing season and having medium to black soils. With the availability of improved rain-fed technologies like rainwater management, choice of crops, and agronomic practices, a greater proportion of rain-fed lands can be brought under intensive cropping system.

### 10.3.4 Choosing Appropriate Sowing Window and Seed Rate

Farmers choose a sowing window, mainly depending on the rainfall, in situ soil moisture, and normal timing in the season. Their considerations include sufficient or excess soil moisture to affect seed germination, expected dry spells in the season, planning for second season crop, and crop productivity. Informed decision-making AU35 to increase cropping intensity in a favorable season using skill of probabilistic rainfall forecast and crop modeling to help farmers improve crop productivity by increased use of nutrient inputs efficiently. In rain-fed systems, managing required population is a critical issue. It is evident that sufficient seed rate in case of groundnut, soybean, and chickpea can significantly enhance crop yields; however, due to higher seed costs as well as prospects of low rainfall or soil moisture, farmers tend to adopt low seed rate resulting in sparse population and low productivity especially with rain-fed crops. Maintaining optimum seed rate and plant population significantly improves crop productivity.

Intercropping with grain legumes is one of the key strategies to improve productivity and sustainability of rain-fed agriculture. Productive intercropping options identified to intensify and diversify rain-fed cropping systems are:

- Groundnut with pigeon pea.
- Pigeon pea with maize.
- Pigeon pea with soybean.

Some of the other interventions are ridge planting systems; seed treatment; AU36 integrated pest management (IPM); and adoption of improved crop varieties and production technologies, promoting community-based seed production groups and market linkages. Farmers need to be encouraged to practice seed treatment with *Trichoderma* spp. and fungicides for managing seedling diseases and IPM options for controlling pod borer in chickpea and pigeon pea. Improved water use efficiency through integrated water management (IWM) is the key in rain-fed agriculture. Alternative sources of irrigation water are the carefully planned reuse of municipal wastewater and drainage water.

ICRISAT assessed several sequential and intercrop systems on different soil AU37 types and recorded a yield advantage ranging between 20 and 35% with maize/pigeon pea and green gram/black gram/pigeon pea intercrop systems and yield advantages ranging from 20 and 50% with maize-chickpea, paddy-chickpea, and paddy-black gram/green gram sequential systems compared to sole crop traditional systems in different years. On Alfisols, groundnut/millet and groundnut/pigeon pea

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intercrop systems were evaluated for enhancement of productivity and recorded yield advantages ranging between 10 and 25% in long-term experiments.

### 10.3.5 Seed Treatment

Seed treatment with fungicide and insecticide is desirable to avoid damage to germinating tender seedlings from seed-borne or soil-borne fungi and insects. If seed treatment is done with systemic fungicides or systemic insecticides, seedlings will be protected from diseases or insects for a month. Generally, seeds are treated with imidacloprid at the rate of 2 mg $kg^{-1}$ to control sucking insects like jassids and aphids and chlorpyrifos at the rate of 4 ml $kg^{-1}$ of seed to control soil-borne insects. Mancozeb at the rate of 3 gm $kg^{-1}$ or carbendazim at the rate of 1 gm $kg^{-1}$ of seed will be sufficient to control fungal diseases. Combination of fungicides is also recommended in seed treatment module, where seed treatment with thiram and carbendazim (1:1) at the rate of 2.5 g $kg^{-1}$ was found to be the effective component in groundnut IDM. Seed of legume crops should be treated with crop-specific efficient biological nitrogen-fixing bacterial (*Rhizobium*) cultures. In order to enhance fixation, appropriate tillage and balanced nutrient management methods should be adopted for surface soil to provide good aeration. Leveled fields with gentle slope no water stagnation even after high rainfall events are desirable to facilitate good aeration and higher N fixation in the root zone. Seed priming is another technique used to improve seed distribution at sowing and for good germination and also exerts drought tolerance in crops.

### 10.3.6 Crop Water Requirement and Water Management

Dryland crops vary widely in their water requirement for crop growth and maturity. Besides soil type, rainfall, and temperature in the region, which determine length of crop-growing period, crop water requirement is critical to plan crops and cropping systems appropriate for a region. Knowledge on critical growth stages of crops, those that can be affected by water deficit resulting in varying degree of crop yields, is very important to effectively use available water in rain-fed situations.

### 10.3.7 Weeding and Intercultural Operations

Weeding and intercultural operations are most important in dryland farming, as higher-density weed population compete and efficiently steal the valuable scarce soil nutrients and moisture affecting cultivated crops. It is estimated that weeds on an average cause 20% crop production loss in India. Interculture for inter-row weeding

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and soil mulching to prevent moisture loss from lower layers, which is very important for rain-fed crops frequently affected by long dry spells. Initially slow-growing and low-population crops like pigeon pea, green gram, black gram, etc. are more prone to weed infestation. Besides intercultural operations, control measures include crop rotation, of crop holidays are some cultural measures. Although chemical control measures are expensive, they are effective, and some chemicals are selective in timing and crop specific also. Pre-emergence herbicides and post-emergence crop-specific herbicides are also available. AU41

### *10.3.8 Crop Diversification*

The main objective is to enhance the farm income by targeting crop diversification and intensification through suitable cropping systems management. The diversification will be targeted by two ways: first by crop diversification and second by agricultural diversification.

In India, crop diversification is generally viewed as a shift from traditionally grown less remunerative crops to more remunerative crops. It is intended to give a wider choice in the production of a variety of crops in a given area so as to expand production-related activities on various crops and also to help in reducing risk in agriculture. The legumes are best fit to crop diversification. The introduction of new compatible crop as well as improved varieties of selected crop with appropriate production technology enables the farmers to diversify their systems. The aim is to enhance plant productivity, quality, health, and nutritional value and/or build crop resilience to diseases, pest organisms, and environmental stresses. AU42

Agricultural diversification is a process of a gradual movement out of subsistence food crops (particularly staple foods) toward diversified market-oriented crops that have a larger potential for return. This process is triggered by the availability of improved rural infrastructure, rapid technological advancements in agricultural production, and changing food demand patterns. Hence, this process of diversification toward high-value crops is likely to accelerate agricultural growth and usher in a new era of rural entrepreneurship and generate employment opportunities.

### *10.3.9 Crop Intensification*

Large areas with Vertisols like in Madhya Pradesh are kept fallow during rainy season or following paddy cultivation in Indo-Gangetic Plains (IGPs) in spite of availability of soil moisture largely due to poor adoption of land and water management technologies as well as short-duration high-yielding cultivars. In Madhya Pradesh alone, two million ha area with Vertisols and assured rainfall is kept fallow during the rainy season due to anticipated crop losses because of waterlogging and delayed sowing of post-rainy season crop (Wani et al. 2002a). However, BBF and

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use of short-duration cultivars of soybean and adoption of minimum tillage for the *rabi (*post-rainy) season crop have enabled cultivation of these Vertisols with two crops (soybean + wheat or chickpea) (Wani et al. 2002a, Wani et al. 2012c).

Enhancing the cropping intensity through managing the existing cropping system either through vertical or horizontal expansion will be focused in both the regions. Basically the crop intensification has been done with the introduction of legumes in the existing cropping system either through vertical integration or horizontal integration. The major constraints include lack of short-duration cultivars, soil fertility decline, and poor agronomic practices. Diversification/intensification should be taken place either through area augmentation or by crop substitution. If carried out appropriately, it can be used as a tool to augment farm income, generate employment, alleviate poverty, and conserve precious soil and water resources. Major driving forces for crop diversification/intensification targeted are increasing income on small farm holdings; mitigating effects of increasing climate variability; balancing food demand; improving fodder for livestock animals; conservation of natural resources; minimizing environmental pollution; reducing dependence on off-farm inputs; depending on crop rotation; decreasing insect pests, diseases, and weed problems; and increasing community food security.

#### 10.3.9.1 Crop Intensification Through Rainy Season Fallow Management

Rainy season fallow management Vertisols and associated soils, which occupy large areas globally (approximately 257 m ha; Dudal, 1965), are traditionally cultivated during post-rainy season on stored soil moisture due to waterlogging-associated risks during the rainy season caused by poor infiltration rates. The practice of fallowing Vertisols and associated soils in Madhya Pradesh, India, was perceived to be decreased after the introduction of soybean; however, 2.02 mha of cultivable land is still kept fallow in central India, during the *kharif* season (Wani et al. 2002; Dwivedi et al. 2003). However, the survey also indicated that rainy season soybean area expansion only replaced sorghum areas and fallows remained fallow because rainy season crop delays the sowing of post-rainy (*rabi*) crop, forcing the farmers to keep the cultivable lands fallow, thus reducing WUE and enhancing soil erosion. Through watershed on-farm participatory research, ICRISAT demonstrated the avoidance of waterlogging during initial crop growth periods on Vertisols by preparing the fields as BBF along with grassed waterways. Simulation studies using the SOYGRO model showed that early sowing of soybean in 7 out of 10 years was possible by which soybean yields can be increased threefold along with appropriate nutrient management. Hence, evolving timely sowing with short-duration soybean genotypes could pave the way to successful post-rainy season crop where the moisture-carrying capacity is sufficiently high to support it. On-farm soybean trials conducted by ICRISAT involving improved land configuration (BBF) and short-duration soybean varieties along with fertilizer application (including micronutrients) showed a yield increase of 1300–2070 kg/ha compared with

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790–1150 kg/ha in Guna, Vidisha, and Indore districts of Madhya Pradesh. Increased crop yields (40%–200%) and incomes (up to 100%) were realized with landform treatment, new varieties, and other best-bet management options (Wani et al. 2008). On-farm trials on conservation tillage were conducted with short-duration soybean in Madhya Pradesh (Guna, Vidisha, and Indore districts) to intensify the kharif fallow areas using suitable landform management (broad bed furrow system). The trials then adopted zero-till planters to sow the succeeding rabi chickpea with minimum tillage to enhance the cropping intensity. The results revealed increased crop yields (40–200 percent) and incomes (up to 100 percent) using landform treatments, new varieties, and other best-bet management options (Wani, Joshi and Raju, 2008) through crop intensification. So, for better utilization of residual soil moisture, practices such as zero/minimum tillage and relay planting are recommended. Specially designed machinery, such as the zero-till multi-crop planter, can be used effectively to sow in paddy fallow without severely affecting soil moisture.

#### 10.3.9.2 Rice-Fallow Management for Crop Intensification

In Southeast Asia, paddy is mostly grown in the *kharif* season. A substantial part of this area (15 million ha) remains fallow during the *rabi* (post-rainy) season, primarily due to limited soil moisture availability in the topsoil layer for crop establishment (Subbarao et al. 2001). Paddy fallow is the land used to grow paddy in the *kharif* season but is left uncropped during the following *rabi* season. Of the total paddy fallow area in South and Southeast Asia, 2.11 million ha (33 percent of the *kharif* paddy-growing area) is in Bangladesh, 0.39 million ha (26 percent) is in Nepal, and 11.65 million ha (29 percent) is in India. Since paddy is grown on some of the most productive lands in this region, there is scope for increasing the cropping intensity by introducing a second crop during the *rabi* season using appropriate technologies.

The exact area under paddy fallow per country in Southeast Asia is not available but is needed to plan sustainable intensification. In South Asia, there is approximately 15 million ha of paddy fallow, which is nearly 30 percent of the paddy-growing area. In India, nearly 82 percent of the paddy fallow is located in the states of Assam, Bihar, Chhattisgarh, Madhya Pradesh, Orissa, and West Bengal. GIS analysis of this fallow land identified diverse soil types and climatic conditions (Kumar Rao et al. 2008). The available soil water holding capacity (1 m soil profile) for most of this land ranges from 150 to 200 mm (Singh et al., 2010). If we assume that these soils are fully saturated during most of the paddy-growing season, then there will be residual moisture in the soil at paddy harvest that could be used by the following crop. Wani et al. (2009a) reported that these paddy fallows offer a potential niche for legume production due to the considerable amount of available green water after the monsoon, which could be used by a short-duration legume crop after simple seed priming and micronutrient amendments (Kumar Rao et al. 2008; Singh et al. 2010).

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Paddy fallow is an underutilized resource of poor farmers with subsistence agricultural practices largely due to biophysical, production, and socio-economic constraints to cultivate the second crop in paddy fallow. Biophysical constraints comprise the persistence of rain-fed ecology, high runoff and low moisture storage, water stagnation/excessive moisture in coastal regions, and low residual moisture in dry regions which are the main biophysical limitations. Development of deep cracks during drying of soil, compaction of topsoil layer due to puddling in paddy fields, low soil organic matter content, and poor microbial activity are other factors. Narrow sowing window for second crop, lack of short-duration and high-yielding varieties, poor plant stands due to poor soil-seed contact in relay sowing, lack of fertilizers/chemicals, severe weed infestations including parasitic weeds, high incidence of diseases, moisture stress, and terminal drought are important production constraints. Socio-economic constraints include letting loose animals to open graze after the harvest of paddy, resource-poor farmers, lack of credit and market infrastructure, non-availability of critical inputs such as suitable machinery, and scarcity of human labor after paddy harvest due to migration to urban areas.

As global warming sets in, agricultural production worldwide is projected to fall by 2 percent per decade, as food demand increases by 14 percent. Global bodies are pushing for climate-smart farming with smart crops in a bid to reduce the carbon footprint of agriculture. Dryland grain legumes are branded as smart food crops (ICRISAT, 2017) in which consumers, farmers, and the planet benefit as they diversify farming systems and help smallholder farmers adapt to climate change. Climate change is already affecting crop production, which will impact farmer livelihoods and food availability. So climate-smart crops and management offer sustainable options to farmers to both adapt to and mitigate climate change (FAO, 2017), and such locally produced, nutrient-rich, climate-smart/climate-resilient crops are referred as Future Smart Foods (FSFs) by the FAO (2017). The FSFs include a variety of warm-season legumes (e.g., black gram, groundnut, mungbean, pigeon pea, soybean) and cool-season legumes (e.g., chickpea, faba bean, *Lathyrus*, lentil, pea).

A considerable amount of green water is available after the monsoon, especially in rice-fallow systems, which could easily be utilized by introducing a short-duration legume crop with simple seed priming and micronutrient amendments (Subbarao et al. 2001; Kumar Rao et al. 2008; Wani et al. 2009a; Singh et al. 2010). Taking advantage of sufficient available soil moisture in the soil after harvesting rice crop during the cool season in eastern India and growing of early maturing chickpea in rice-fallow areas with best-bet management practices (minimum tillage for chickpea, seed priming of chickpea, 4–6 h with the addition of sodium molybdate to the priming water at 0.5 gL/kg seed and *Rhizobium* inoculation at 5 g/kg seed, micronutrient amendments, and use of short-duration rice cultivars during rainy season) resulted in chickpea yields of 800–850 kg/ha (Harris et al. 1999; Kumar Rao et al. 2008). An economic analysis has shown that growing legumes in rice-fallows is profitable for the farmers with a B/C ratio exceeding 3.0 for many legumes. Also, utilizing rice-fallows for growing legumes could result in the generation of 584 million person-days of employment for South Asia.

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**Table 10.8** Evaluation of chickpea cultivars in paddy fallows in Jharkhand during 2010–2013

| District | Block | Crop | Variety | Yield (kg $ha^{-1}$) |
|---|---|---|---|---|
| Gumla | Raideh | Chickpea | KAK 2 | 1520 |
| | | | JG 11 | 1340 |
| Seraikella-Kharsawan | Sariekela | Chickpea | KAK 2 | 1490 |
| | | | JG 11 | 1280 |

The scaled-up on-farm research showed that short-duration pulses are suitable for cultivation in paddy fallow and yield well, provided that suitable varieties and technologies (including mechanization for crop establishment) are available. Participatory trials in Jharkhand state with the purpose of demonstrating and evaluating chickpea cultivars (JG 11 and KAK 2) in post-rainy fallow yielded 1490–-1520 kg $ha^{-1}$ for KAK 2 and 1280–1340 kg $ha^{-1}$ for JG 11 (Table 10.8), which indicates that chickpea is a suitable crop to grow after paddy with the benefit of additional income and enhanced rainwater use efficiency. An economic analysis showed that growing legumes in paddy fallows is profitable for farmers, with a benefit-cost ratio of >3.0 for many legumes. Such systems could generate 584 million person-days of employment for South Asia and make the region self-sufficient in pulse production. In a number of villages in the states of Chhattisgarh, Jharkhand, and Madhya Pradesh in India, on-farm farmers' participatory action research trials sponsored by the Ministry of Water Resources, GoI, showed significantly enhanced RUE through cultivation of rice-fallows with a total production of 5600–8500 kg/ha for two crops (rice + chickpea), benefiting the farmers with increased average net income of Indian rupees 51,000–84,000 (USD 1130–1870/ha) (Singh et al. 2010).

Similarly, Parthasarthy et al. (2010) observed that cultivation of legumes improves soil fertility and has follow-on beneficial effects on paddy performance. Soil-building integrated approach promoted in study sites emphasized recycling of local materials and reduced reliance on external inputs. In Chhattisgarh, the on-farm participatory research trials sponsored by the Ministry of Water Resources revealed that the introduction of best management practices, viz., zero tilled sowing of *rabi* crops, seed priming, etc., in paddy-based cropping systems enhanced rabi crop productivity and thereby total system productivity. Early sowing of paddy along with good management practices increased paddy productivity by 8–29% (Table 10.9) with scope for cultivation of *rabi* crops on the residual moisture.

In an initiative supported by the Department of Agriculture, Co-operation and Farmers Welfare (DAC&FW) in India, ICRISAT focused on crop intensification in paddy fallows through the introduction of chickpea, bringing in three million ha of paddy fallow from the eastern state under FSF crops. DAC&FW along with ICRISAT conducted a national-level workshop at Bhubaneswar for scientists, researchers, farmers, and policymakers on the introduction of FSF crops to existing single cropping of paddy. In 2016/2017, a DAC&FW-led consortium introduced chickpea to almost 1.8 million ha along with best management practices, including seed priming and mechanized sowing with zero-till multi-crop planters with minimal

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**Table 10.9** Percent increase in paddy and chickpea yields with improved management from 2007–2008 to 2008–2009

| District | Number of farmers involved | Area sown (ha) | Biomass yield (kg ha$^{-1}$) | | Grain yield (kg ha$^{-1}$) | | % increase in grain yield |
|---|---|---|---|---|---|---|---|
| | | | Trade | Import | Trade | Import | |
| Paddy (kharif season) | | | | | | | |
| Ambikapur | 48 | 15 | 11,110 | 12,460 | 5520 | 5970 | 8.1 |
| Kanker | 36 | 15 | 12,930 | 14,880 | 6090 | 7370 | 20.9 |
| Bastar | 18 | 15 | 8260 | 10,100 | 3910 | 5060 | 29.4 |
| Chickpea (rabi season) | | | | | | | |
| Ambikapur | 28 | 4.8 | – | 480 | – | 220 | – |
| Kanker | 80 | 19.7 | – | 1980 | – | 1140 | – |
| Bastar | 41 | 14.3 | – | 1020 | – | 540 | – |

tillage. The farmers harvested 650–800 kg per hectare of chickpea with net economic benefits ranging from INR 15000 to 20,000 per hectare.

### *10.3.10 Weed Management*

Weeds are one of the major biological constraints which can cause up to 33 percent crop losses and also act as alternate hosts for pathogens, insects, and nematodes. Weeds compete with crops for land, water, and light as well as added inputs and reduce yield and quality. Suitable integrated weed management strategies are a must for enhancing productivity of legumes.

## 10.4 Empowering Farmers Through Knowledge, Science, and Technology

Application of digital tools such as remote sensing, geographical information systems, telemetric sensors, and several decision support systems in agriculture is, often, not making cross-over beyond academics or used only in planning process at country or state level. Among these, however, communication technologies are strengthening the agricultural extension system as both government department and private companies have invested in business of agriculture knowledge dissemination services. The key advantage of all these technologies is the solution to large-scale farming community, for example, identifying moisture stress area in a country using remote sensing technology for preparing plan to assist farmer in supplementary irrigation or even declaring drought. The following are the few examples of digital tools in agriculture.

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### 10.4.1 Identifying Suitable Land for Crop Cultivation

Soils, weather, and water availability have great influence on crop productivity. Soil-site suitability studies have provided the criteria to select the suitable crops for given piece of land. This helps to find out specifically the suitability of the land resources like soil-site characteristics, water, weather, climate, and other resources and the type of constraints that affect the yield and productivity of the selected crop. The National Bureau of Soil Survey and Land Use Planning (NBSS&LUP), India, has prepared manual on soil-site suitability criteria for major crops (Naidu et al. 2006). In this assessment, the specific requirements of a crop are compared with the characteristics of land, and suitability of the area for the crop is arrived based on the matching. If the land characteristics of an area match the requirements of the selected crop, then the area is considered as suitable for the crop; otherwise it is grouped as not suitable for the crop. The site-specific land resources database helps to establish the suitability of the resources to any selected crop for the area in a very objective manner, which was not possible earlier with general datasets.

The applicability of this approach to large extent is limited due to unavailability of high-resolution spatial information of soil properties. However, this methodology is being piloted at micro-watershed scale in selected district of Karnataka state under a World Bank-supported project. The high-resolution maps provide more detailed information, but it may not be feasible to analyze a soil profile per 1 hectare area. Digital soil mapping (DSM) – or predictive soil mapping – provides option to generate soil property surfaces at fine resolution with the uncertainty of prediction. Digital soil mapping uses field and laboratory observation method such as proximal soil sensing (Viscarra Rossel et al. 2011) and soil spectroscopy (Nocita et al. 2015) as input to predictive model that provides soil maps. A global consortium is working together to make a new digital soil map of the world using state-of-the-art and emerging technologies for soil mapping and predicting soil properties at fine resolution (GSM, 2017). Although the DSM product has some prediction uncertainties, it provides the spatial information at much higher resolution and at less cost. The crop suitability maps at large extent have been successfully implemented by Tasmania using digital soil mapping to generate high-resolution soil maps (Kidd et al. 2014a; Kidd et al. 2014b) (Fig. 10.4). The web application is available in public domain.[1]

### 10.4.2 Weather-Based Agro-advisories

The information required for giving weather-based advisories are historic weather data, current observed weather data, forecast weather, soil characteristics, and crop management details. An algorithm for moisture adequacy index (MAI) will consume

[1] http://maps.thelist.tas.gov.au/listmap/app/list/map?bookmarkId=216124

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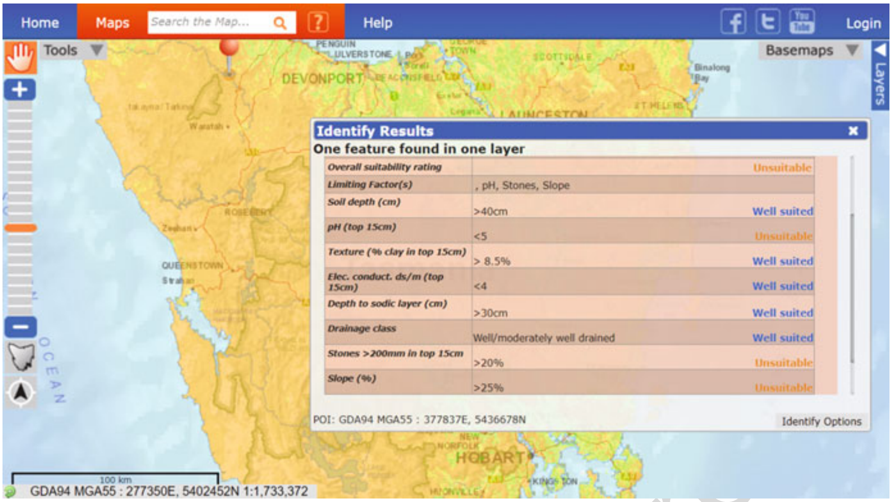


**Fig. 10.4** Enterprise suitability maps of Tasmania

required data from data cloud and provide probable moisture status. Based on moisture status and weather forecast, suitable advisories are being given to farmers regarding crop sowing window and irrigation requirement. ICRISAT in collaboration with Microsoft has piloted weather-based advisories to farmers in selected villages in Andhra Pradesh (ICRISAT, 2017). The advisories have helped farmers achieve optimal harvests by suggesting the best time to sow crops depending on weather conditions, soil, and other indicators. This algorithm utilizes extensive data including soil characteristics, rainfall over the last 45 years, as well as 10 years of groundnut sowing progress data for Kurnool district of Andhra Pradesh. This data is then downscaled to build predictability and guide farmers to pick the ideal sowing week. This advisory is being scaled up in selected districts of Andhra Pradesh, Telangana, and Karnataka covering more than 3500 farmers.

## 10.4.3 *Irrigation-Based on Crop Water Requirement*

Inappropriate management of water resources and irrigation methods results in low crop yields and poor water use efficiency (WUE). The irrigation methods and irrigation strategies are important factors for improving WUE. Improved method AU50 of irrigation system Despite water scarcity in most farmers' fields in semi-arid tropic locations, water is carried through open channels, which are usually unlined and, therefore, a significant amount of water is lost through seepage. In India, farmers irrigate land rather than crops. For example, for Alfisols and other sandy soils with more than 75 percent sand, practices may include the lining of open field.

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A number of tools are available for simulation of water balance, crop growth, and yield. Moreover, some of the tools/models are exclusively developed for designing irrigation scheduling. But use of these tools is mainly limited to the scientific community due to complex parameterization. ICRISAT has developed a simple MS Excel-based tool "water impact calculator" using strategic research data collected at ICRISAT and validated at three pilot sites situated into three Indian states (Rajasthan, Gujarat, and Andhra Pradesh). This tool needs very basic data as an input AU51 which users easily can provide and provides simple actionable information as how much water is needed to be applied on what date. Moreover, this tool allows user to update rainfall and applied irrigation values so that the future irrigation scheduling gets adjusted as per the estimated soil moisture storage. Availability of a decision-making tool which is simple to use and technically robust will help farmers for applying irrigation as per need rather than adapting the calendar-based irrigation schedule. Current water use efficiency (WUE) in agriculture (rain-fed and irrigated) can be doubled from 35–50 percent to 65–90 percent with large-scale interventions of scientifically proven management (land, water, crop, and pest) options. The Pradhan Mantri Krishi Sinchai Yojana (PMKSY) scheme of the Government of India enables the handling of green and blue water resources together by adopting holistic and integrated water management approaches (Wani et al., 2012, Wani et al., 2016). It is important that all components of the PMKSY scheme be implemented together in rain-fed or irrigated areas with micro-watersheds as an implementing unit in the districts. Measures to enhance WUE are discussed elsewhere in this chapter and are reiterated here for continuity:

- Efficient use of rainwater stored in soil as soil moisture (green water).
- Conjunctive use of blue water through rainwater harvesting in farm ponds.
- Improved landform for efficient irrigation and water management.
- Protected cultivation of high-value crops.
- Soil test-based integrated nutrient management.
- Improved crop management practices.
- Efficient irrigation using micro-irrigation (zero-flood irrigation).
- Water balance-based irrigation scheduling in place of calendar-based irrigation scheduling.
- Crop rotations and intercrops.
- Improved crop cultivars (drought tolerant and water efficient).
- Integrated pest and disease management.
- Enabling policies and innovative institutional mechanisms.
- Organic matter amendments through in situ generation of green manuring and composting (vermicomposting and aerobic composting).
- Minimum tillage, channels with some hard cementing material, covering of channels with solar panels as in Gujarat, or using irrigation pipes to reduce high seepage and evaporation water losses and enhance productivity and profitability.

The use of closed conduits (plastic, rubber, metallic, and cement pipes) should be promoted (Pathak, Sahrawat and Wani, 2009) to achieve high WUE. Micro-irrigation, in general, is practiced for high-value and horticulture crops. Similarly, micro-

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irrigation in field crops, including paddy-based cropping systems, should be promoted on a large scale to address the issue of groundwater depletion and water scarcity. Some field trials undertaken in Raichur under the Bhoosamruddhi program on drip irrigation in paddy revealed that growth parameters (plant height, tiller number, soil plant analysis development, and leaf area) improved significantly under sub-surface and surface drip irrigation with laterals spaced 60 cm apart. The highest grain yields of paddy of 10.1 and 9.0 tonnes per hectare were recorded in direct-seeded paddies compared with transplanted paddy under surface drip irrigation with laterals placed 80 cm apart and 60 cm, respectively (Bhoosamruddhi Annual Report, 2016).

Similarly, drip irrigation trials in wheat at Tonk and Udaipur, Rajasthan, and Mota Vadala, Gujarat, showed that 40–50 percent of water could be saved using improved irrigation techniques. For water-loving crops, including sugarcane and banana, it is necessary to popularize water-saving technologies, such as drip irrigation, by making them mandatory. In Jharkhand, to use the available water efficiently, drip irrigation was promoted by ICRISAT for vegetable cultivation in Teleya village in Gumla district, which increased the net profit to farmers from Rs 8000 to Rs 10,000 per acre.

### *10.4.4 Information and Communication Tools for Information Dissemination*

Dissemination of agricultural knowledge up to the small and marginal farmers has been weak link in agriculture. Farmers require actionable information at right time to take decision and plan for action. Moreover, market players also require similar information so that market will be ready to cater farmers' demands. In fact, few input providers have initiated the advisory services on subscription basis to provide information as well as promote their product. Similar to subscription model, various ways are being implemented to increase the outreach of extension system.

In India, the government has Kisan Call Center (KCC) facility to provide information as per farmers' demand in 22 local languages. The government has brought all the tools for disseminating agriculture knowledge under one umbrella mKisan.[2] The services provided through this website are Unstructured Supplementary Service Data (USSD) and SMS-based dissemination, pull and push SMS, interactive voice response system (IVRS), KCC, and android-based applications. In addition to the government, private companies are also providing innovative solutions for agriculture extension. For example, IFFCO Kisan Sanchar Limited has introduced voice messages for agro-advisory system, and Thomson Reuters introduced mobile-based integrated agro-advisory system "Reuters Market Light."

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[2] www.mkisan.gov.in

One of the best ways to convince farmers regarding the improved farming practices is through demonstrating those technology in their fields – “seeing is believing.” But this may not be the solution for outreaching millions of farmers. An alternative solution for this initiated by a private organization Digital Green is sharing farmer’s experience of improved farming practices to group of farmers through video documentation. The advantage of this farmer to farmer (F2F) information dissemination method is the fact that farmers trust fellow farmers to adopt improved management practices. Farmers can easily understand these farming practices as they explain in their languages. Farmer shares his/her experience about the technology on camera. These short videos are screened to small gathering (20–30 farmers) in villages using battery-operated small projectors.

## 10.5 Legumes: Key Component in Doubling Farmers’ Incomes

Dryland grain legumes branded as Smart Food Crops (ICRISAT, 2017) are good for consumers, farmers, and the planet as they diversify farming systems and help smallholder farmers adapt to climate change. As we know unpredictable and erratic AU53 climatic patterns resulting from climate change are affecting crop production. This will have an impact on farmer livelihoods and food availability. So climate-smart crop and management provides sustainable options to farmers to both adapt to and mitigate climate change. Such climate-smart/climate-resilient crops are referred as Future Smart Foods (FSFs) by the FAO (2017).

The pulse production is facing an enormous underutilized resource base with subsistence agricultural practices. To be precise, there are different constraints in harnessing the potential yield of pulses which are characterized into three main heads, viz., biophysical, production, socio-economic. Looking at the situational analysis of the above aspects, our focus needs to be on bringing in vertical integration in the existing legumes-based cropping systems to meet the increasing food demand. Efforts need to be made to analyze the current status of legumes’ produc- AU54 tivity, assess the potential for intensifying the cropping system, and propose a new paradigm to enhance agricultural productivity per unit area through introducing best-bet agronomic management practices with a holistic management approach and operationalize the integrated genetic natural resource management (IGNRM) strategy. Based on our hands-on experiences in India for harnessing the untapped potential of rain-fed legume areas, it can be proposed that legumes can play an important role in doubling the farmers’ income through increase in total food production and thereby improvement in the livelihoods of people with finite and scarce resource through enhanced resource use efficiency.

Under National Food Security Mission in paddy fallow areas of Kalaghatagi taluk AU55 to popularization of improved green gram variety IPM 02–14 (Shreya) was demonstrated during *rabi* season of 2015–2016. Introduction of high-yielding variety,

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transfer of improved production package (seed treatment with bioagents, viz., *Rhizobium*, *Trichoderma*, phosphate solubilizing bacteria (PSB), 2% DAP (diammonium phosphate) spray at flowering and pod initiation stage), and use of integrated pest management practices proved beneficial. The improved variety IPM 02–14 (Shreya), being a short-duration (75 days) variety resistant to yellow mosaic virus and crinkling disease, helped the farmers to plan the third crop even in the summer season, improving the economy of the farming community. The adoption of new variety through the intervention of Krishi Vigyan Kendra, Saidapur Farm, Dharwad, in the cluster approach enhanced the productivity leading to sustainable income annually. This has not only resulted in socio-economic security but also helped in attaining food and nutrition security of the community along with the fodder requirement of farm animals (www.kvkdharwad.org.)

To empower farmers in the pigeon pea and chickpea production during 2007, IIPR (Indian Institute of Pulses Research), Kanpur, implemented a project on "Model Seed System(s) in district Fatehpur." The interaction between scientists and farmers heightened the ability to grow mungbean after rice-wheat cropping system. Field demonstration of successful summer mungbean at IIPR farm encouraged farmers to opt for it. The farmers of Mauhar and Alipur villages of Malwan block of Fatehpur district came forward to start mungbean cultivation in summer. In 2008 mungbean was grown after mustard under the guidance of the IIPR scientists. The farmers harvested 12–14 q/ha mungbean in 65 days and earned Rs 50–60 thousand/ha. The mungbean variety Samrat yielded 13.5 q/ha and Meha 14.0 q/ha. From the total produce of 48q, Mr. Patel earned Rs 1,76,000 with an investment of Rs 28,000 only. The farmers of Mauhar and Alipur villages have opted cultivation of summer mungbean as they are fully confident of bonus yield and monetary gains from summer mungbean without affecting their current rice-wheat cropping system (https://www.icar.org.in/node/250.)

## 10.6 Legumes and Sustainable Development

Legumes have an important role in sustainability of cereal-based cropping system through N fixation in the soil. Cropping systems, in which legumes are component, are found to sequester huge quantities of atmospheric $CO_2$. Long-term studies at ICRISAT (Wani et al., 2003) showed that improved system comprising landform management (broad bed and furrow cultivation), soil test-based balanced fertilization, and crop management significantly increased soil organic C content. In this historical study, an additional quantity of 7.3 tons C per ha (335 kg C per ha per year) was sequestered in soil under the improved system compared with the traditional system over the 24-year period. Leguminous plants are considered to have a competitive advantage under global climate change because of increased rates of symbiotic N fixation in response to increased atmospheric $CO_2$ (Serraj, 2003; Wani et al. 2003).

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# Author Queries

Chapter No.: 10 466053_1_En

| Query Refs. | Details Required | Author's response |
|---|---|---|
| AU1 | Please check and confirm if the affiliations are presented correctly. | |
| AU2 | In abstract, please check if edit to sentence starting "Soil health mapping. . ." is okay. | |
| AU3 | All occurrences of "Death Valley" have been changed to "death valley". Please check if okay. | |
| AU4 | In keyword, please check if "Information and communications technology" is okay as edited. | |
| AU5 | In keyword, please check "?" for significance. | |
| AU6 | Please check if edit to sentence starting "During the years. . ." is okay. | |
| AU7 | Please check if edit to sentence starting "The Food and. . ." is okay. | |
| AU8 | Please check if edit to sentence starting "However, it's a. . ." is okay. | |
| AU9 | Please check if "ICEs" should be changed or be retained as is. | |
| AU10 | Please check if edit to sentence starting "Appropriate landform applications. . ." is okay. | |
| AU11 | Please check sentence starting "Infiltration rate when. . ." for clarity. | |
| AU12 | Please check latter part of sentence starting "Furrows made at. . ." for clarity. | |
| AU13 | Please check if edit to sentence starting "In the SAT. . ." is okay. | |
| AU14 | Please check if edit to sentence starting "Even though knowledge. . ." is okay. | |
| AU15 | Please check if latter part of sentence starting "Healthy soils are. . ." should be retained as is. | |

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|---|---|---|
| AU16 | Please check if "Santhipuram" is okay as edited. | |
| AU17 | Please check if "Ranasthalam" should be changed to "Ranastalam". | |
| AU18 | All occurrences of "Badwani" have been changed to "Barwani". Please check if okay. | |
| AU19 | Please check if "Ramanagra" should be changed to "Ramanagara". | |
| AU20 | Please check sentence starting "As indicated earlier..." for clarity. | |
| AU21 | Please check if edit to sentence starting "Worldwide legumes constitute..." is okay. | |
| AU22 | Please check if edit to sentence starting "Pre-breeding is one..." is okay. | |
| AU23 | Please check if edit to sentence starting "Selection intensity and..." is okay. | |
| AU24 | Please check if edit to sentence starting "LeasyScan phenotyping platform..." is okay. | |
| AU25 | Please check if edit to sentence starting "Secondly, this farmers'..." is okay. | |
| AU26 | Please check if edit to sentence starting "Similarly, emphasis was..." is okay. | |
| AU27 | Please check "Participatory" for significance. | |
| AU28 | Please check if edit to sentence starting "The layout of..." is okay. | |
| AU29 | Please check latter part of sentence starting "The efforts were..." for clarity. | |
| AU30 | Please check if "Chikmagalur" is okay as edited. | |
| AU31 | Please check if "Chamarajanagar" is okay as edited. | |
| AU32 | Please check sentence starting "Based on the..." for clarity. | |
| AU33 | Please check sentence starting "In medium-deep..." for completeness. | |
| AU34 | Please check if "endemic pests and diseases" is okay as edited. | |

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| AU35 | Please check sentence starting "Informed decision-making to..." for completeness. | |
| AU36 | Please check if edit to sentence starting "Some of the..." is okay. | |
| AU37 | Please check if edit to sentence starting "ICRISAT assessed several..." is okay. | |
| AU38 | Please check if edit to sentence starting "Combination of fungicides..." is okay. | |
| AU39 | Please check if edit to sentence starting "Seed priming is..." is okay. | |
| AU40 | Please check sentence starting "Interculture for inter-row..." for completeness. | |
| AU41 | Please check sentence starting "Besides intercultural operations..." for clarity. | |
| AU42 | Please check if edit to sentence starting "The aim is..." is okay. | |
| AU43 | Please check if edit to sentence starting "Biophysical constraints comprise..." is okay. | |
| AU44 | Please check if edit to sentence starting "Dryland grain legumes..." is okay. | |
| AU45 | Please check if edit to sentence starting "Taking advantage of..." is okay. | |
| AU46 | Please check if "Sariekela" should be changed to "Saraikela". | |
| AU47 | Please check if "zero tilled sowing" should be changed to "zero-till sowing". | |
| AU48 | All occurrences of "DoAC&FW" have been changed to "DAC&FW". Please check if okay. | |
| AU49 | Please check if edit to sentence starting "The key advantage..." is okay. | |
| AU50 | Please check sentence starting "Improved method of..." for clarity. | |
| AU51 | Please check if edit to sentence starting "This tool needs..." is okay. | |
| AU52 | Please check if "mKisan" is okay as edited. | |

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| AU53 | Please check if edit to sentence starting “As we know. . .” is okay. | |
| AU54 | Please check if edit to sentence starting “Efforts need to. . .” is okay. | |
| AU55 | Please check sentence starting “Under National Food. . .” for clarity. | |
| AU56 | Please check if edit to sentence starting “The improved variety. . .” is okay. | |
| AU57 | Please check if “project on “Model Seed System(s) in district Fatehpur.”” should be changed to “project “Model Seed System(s)” in district Fatehpur.” | |
| AU58 | Please check “1,76,000” for correctness. | |
| AU59 | Please check if “28,000” is okay as edited. | |
| AU60 | Please check if “Ministry of Agriculture, Farmers’ Welfare and Co-operation” should be changed to “Department of Agriculture, Co-operation and Farmers Welfare”. | |
| AU61 | Please check if “governments in India” should be retained as is. | |
| AU62 | References "Chander et al. (2018a), Chander et al. (2016), Chander et al. (2018b), Chander et al. (2014), Chander et al. (2012), Chander et al. (2013a), Chander et al. (2013b), GoI (2017), Google (2017), ICRISAT (2017a), ICRISAT (2017b), Rao Kesava et al. (2013), Sahrawat et al. (2007), Sanchez et al. (2009), Saxena et al. (2018), Upadhyaya et al. (2016), Wani et al. (2014), Wani et al. (2013), Wani et al. (2015a), Wani et al. (2015b)" were not cited anywhere in the text. Please provide in text citation or delete the reference from the reference list. | |

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