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Overview of Dryland Agriculture Research and Achievements in Semi-Arid Region of Karnataka

S.L. Patil[1] and M.N. Ramesha[2]

[1]*ICAR-IIPR, Regional Research Station, Dharwad, 580 005, Karnataka, India*

[2]*All India Coordinated Research Project for Dryland Agriculture Centre, ICAR-Indian Institute of Soil and Water Conservation, Research Centre, Ballari 583 104, Karnataka, India*

Email: slpatil1001@gmail.com

Brief history of the centre

ICAR-IISWC Research centre, Ballari was established in 1954 by Government of India to conduct research on problems related to soil and rainwater conservation on medium to deep black soils of low rainfall region. The All India Coordinated Research Project for Dryland Agriculture Centre was established in 1970-71 at Regional Station, Ballari, Central Soil and Water Conservation and Training Centre (now, Indian Institute of Soil and Water Conservation) and continued up to 1986. Later, the Centre was continued as voluntary Centre from 1998 till 2008. Again in 2018, the Centre was made voluntary Centre in AICRPDA. The domain districts of the Centre are Ballari, Chitradurga, Raichur, Koppal, Gadag, Bagalakote, Yadgir, Kalaburgi and Vijayapura districts of Karnataka.

Agro-climatic zone characteristics

The Centre is located in the Northern Dry Agro-Climatic Zone (Zone-3) of Karnataka, which is divided into five agro-ecological sub regions (ESR), *viz*., Hot arid ecological sub-region (coded as 3), Hot dry semi-arid ESR (6.1), Hot moist semi-arid ESR (6.2), Hot dry sub-humid ESR (6.4) and Hot dry semi-arid ESR (7.1). The zone covers 56 taluks of northern Karnataka and large part of the zone area (2.42 million ha, ~50%) is under hot arid ESR. The Ballari Centre in the semi-arid tropics of South India is located in rain shadow belt with an average rainfall of 520.2 mm year^{-1} occurring in average 32 rainy days. Probability analysis of weekly rainfall suggests assured rainfall between standard meteorological weeks of 37 and 44, which corresponds to the period of September 10 to November 4. This period is considered safe for cropping in deep and very deep black soils of the tract. The sixty-five years of rainfall recorded in the Centre show five years of large-excess rainfall, 16 years of excess rainfall, 29 years of normal rainfall, 14 years of deficient rainfall and one year of large-deficient rainfall, over the average annual rainfall. Both excess and deficient rainfall situation hamper the crop production in the region.

Soils of the region

The soils are classified as 'Vertisols' and fall under the sub orders of 'usterts' and 'pellusterts' and sporadic 'aquerts'. Deep Vertisols in Ballari region possess ESP of 7.0 or more in case of swelling soils, which is detrimental to crop growth due to poor soil physical conditions. The moisture retained at 1/3 and 15 bar suction pressure varies from 36 to 50% and 22 to 25%, respectively. The maximum water holding capacity of these soils varies from 60 to 65% and bulk density from 1.2 to 1.3 Mg m^{-3}. Clay content varies from 32 to 55% and increases with depth. The clay minerals are of montmorillonite and beidellite group with cation exchange capacity (CEC) of 100 cmol (p+) kg^{-1} of clay. Exchangeable sodium percentage varies from 3 to 21% and pH increases with depth (8.0 to 9.2). Soils are well supplied with bases and are poor in humus and extremely deficient in available N and P. Soils are marginal with respect to iron and zinc and deficiency of these micro-nutrients is higher under intensive management/crop cultivation. The major rainfed crops cultivated in the region during *kharif-rabi* seasons are greengram, cowpea, cotton, redgram, sunflower, chickpea, *rabi* sorghum, safflower and coriander.

Significant achievements

Production agronomy

Under production agronomy, the Centre has evaluated optimum sowing time of crops for the back-soil region and also conducted evaluation of hybrids and varieties of various crops, *viz.,* sorghum, safflower, chickpea and redgram (Table 1, 2). Further, plant population studies of the various crops were conducted to adjust plant density according moisture availability in the soil as a drought mitigation strategy. Crops and production practices were evaluated against the prevailing weather conditions in the regions. Best suited crops and associated best production practices were identified (Table 3). A multitude of crops have been screened at different dates of planting to identify crops suited for different contingencies of weather outlined elsewhere (Anonymous, 1980).

Table 1: Optimum sowing/planting time for major crops of the region

Crops	Sowing/optimum planting time
Sorghum	First or second fortnight of September (onset of northeast monsoon)
Fieldbeans, redgram, clusterbean, cowpea, limabean, greengram and soybean	First or second fortnight of September (onset of north east monsoon).
Castor, sunflower and seasmum	First or second fortnight of September
Chickpea	First week and first fortnight of October
Coriander and Safflower	Second week and first fortnight of October

Table 2: Suitable varieties of different crops for Ballari region

Crops	Varieties/Hybrids
Sorghum	**Varieties:** Normal and above-normal rainfall situations: SPV–1359 (*Phulae Yashoda*), SPV–1413, CSV–14R and M35–1 Drought years with late sowing situations: M35–1, Mouli, SPV–1591 and SPV–1359 Hybrids: Normal and above-normal rainfall situations: CSH–13 K&R, SPH–1010, SPH–1077 and SPH–1079 Below normal rainfall situations: CSH–19R, CSH–15R, SPH–1230 and CSH–13K&R Normal and drought rainfall situations: CSH–13K and R and short duration hybrids *viz.,* CSH–15R and CSH–19R
Safflower	A–1, CTV–212, 215, 213, 162, 212, Bly–642, Bly–1022
Chickpea	A–1, ICCC–37, Phule–G-2, DDN–9–3, R–81–1–1 (drought resistant), JG-11 and BGD-103
Redgram	Short duration: IPCL–84031, C–11 Medium duration: PT–221, ICPL–87, Maruthi, T–3

Table 3: Choice of crops and production practices for aberrant weather situations

Crops/production practices	Explanation
Safflower, chickpea and coriander	Ideally suited for late *rabi* sowing
Safflower and *Dolichos lablab*	Whenever profile moisture at sowing time is low due to either failure of *kharif* rains or its erratic distribution or both
Mid-seasonal corrections in plant population (Anonymous, 1980).	*Rabi* sorghum: removing the alternate plant, third plant or third row resulted in a significant 37% yield increase in *rabi* sorghum. Plant population reduction and supplemental irrigation (4 cm depth) resulted increased in sorghum grain and straw yields, respectively Safflower: varied response to population correction commands for recommended seed rate

Intercropping of *rabi* sorghum under different cropping systems in rainfed Vertisols: Traditionally *rabi* sorghum is sown along with either pulses or oilseeds as a mixed crop in the region. Intercropping on a population replacement basis offers scope for enhancing the crop yields, besides acting as insurance against the total failure of either crop. A study conducted (1981–82 to 1984–85) with sorghum (CSV–8R) as the main crop and coriander (local), field bean (CO–7), safflower (A–1) and chickpea (A–1) as intercrops in ratios of 1:0, 1:1, 2:1, 3:1 and 0:1 to find out a suitable crop and its ratio, revealed that during the above normal rainfall years, significantly higher sorghum grain equivalent yields (SGEY) was recorded under sorghum + field beans intercropping (4404 kg ha^{-1} in 1981–82 and 3965 kg ha^{-1} in 1983-84), whereas during normal year (1982–83) sorghum+coriander (2714 kg ha^{-1}) and below normal years (1984–85) sorghum+safflower (1268 kg ha^{-1}) performed better. The sole crop of fieldbeans recorded a higher average SGEY (2798 kg ha^{-1}) and a lower SGEY was recorded in coriander (930 kg ha^{-1}). During the below-normal rainfall year (1984–85), when other intercrops as well as sole crops failed, chickpea recorded higher SGEY (1343 kg ha^{-1}). Therefore, during good rainfall years it was recommended to cultivate sorghum intercropped with field beans when crops are sown in the first/second fortnight of September, whereas, during low rainfall years when sowing gets delayed beyond September, sorghum is to be intercropped with chickpea for higher profitability. Among the ratios, 3:1 (sorghum+chickpea) was beneficial for the region. Of late, due to shift in the rainfall from September (120 mm) to October (140 mm), chickpea alone or chickpea mixed crop with *rabi* sorghum has become more popular by replacing *rabi* sorghum and sunflower due to labour problem for harvesting of sorghum and non-availability of high yielding sunflower cultivars. It has been advised to have crop rotation of winter sorghum with chickpea during normal to above normal rainfall situations for sustaining soil properties with higher crop yields and returns in the region.

Conservation agronomy

Soil and moisture conservation practices: Soil and rainwater conservation measures are required in deep black soils of Northern Dry Zone of Karnataka, adjacent Kurnool and Anantapur districts of Andhra Pradesh, Kovilpatti region of Tamil Nadu, and parts of Southern Maharashtra which are left fallow during the south-west monsoon period, to reduce soil and nutrient losses. Several agronomic and cultural practices have also been evaluated at the Centre for identifying effective soil and rainwater conservation (SWC) measures within the bunded area (inter-terrace level).

Establishment of vegetative cover in *kharif* season: Cereals, legumes, and oilseeds/grasses were evaluated for their suitability, either as cover, grain and/or fodder crops or both over a decade during 1960's. Performance of legumes, i.e., greengram, cowpea, blackgram, *Dolichos*, soybean and clusterbean were poor due to insufficient rains with droughts of different magnitudes. Cultivation of groundnut was found highly risky and non-remunerative in addition to crop harvesting problems in the absence of rains. Therefore, the *kharif* cropping on deep black soils of the Ballari region is not much favourable.

Performance of vegetative barriers: A five years (1989–93) evaluation of vegetative barriers effectiveness showed 19 and 36% lower winter sorghum grain yields in the *khus*/lemon grass and *Leucaena* vegetative barriers when compared to 798 kg ha^{-1} under control. This indicates the non-suitability of vegetative barriers as a soil and rainwater conservation practices in the Ballari region.

Contour strip cropping: Feasibility of contour strip cropping to reduce soil erosion and increase productivity was evaluated with erosion permitting (sorghum and cotton) and resistant (groundnut) crops in 2:1, 3:1 and 4:1 ratio with a view to determine optimum strip ratio. Results indicated that varying proportions of groundnut least affected yields of winter crops. Hence, contour strip cropping was not effective due to poor establishment of monsoon crops in the black soils of Ballari region.

Contour cultivation: Cultivation of crops along the slope leads to losses in fertile top soil, nutrients, and rainwater and does not wet the soil profile and results in lower crop yields. Cultivation of crops on contours in the farmer's fields for three consecutive below-normal rainfall seasons in and around Ballari in deep black soils showed an increase in grain yield by 22% in *Setaria* and 35% in *rabi* sorghum over up and down cultivation.

***In-situ* rainwater conservation practices:** Land treatments like ridge furrows, listing and corrugations alone or with gypsum application registered non-significant increase in sorghum and cotton yields. The magnitude of increase in sorghum yield was 120% (1230 to 2700 kg ha^{-1}) during normal rainfall year compared to above normal rainfall years 35% (2130 to 2870 kg ha^{-1}) with organic trench ridging over control. The inter-terrace bedding system (narrow beds on grade would help to drain out the stagnant water during excess rainfall situations and conserve every drop of rainwater *in-situ* during low rainfall) was beneficial and increased winter sorghum yields by 24% (8 years average) and safflower yields by up to 8% (Average of 7 years) over flatbed sowing. Compartmental bunding (CB) and ridges and furrows (R&F) conserved fertile top soil, rainwater *in-situ* and increased the soil water, nutrients in the profile, and produced higher grain yield by 28% with CB and up to 36% with R&F in winter sorghum during the moderate drought year (2000–01). During severe drought year (2002–03), the grain yield increased by 16% with CB and 20% in R&F with water stress at reproductive stages of crop growth. During above-normal rainfall year (2001-02) the grain yield was higher by 13 and 16% with CB and R&F, respectively. The mean grain yield (average of 3 years) increased by 17% (2122 kg ha^{-1}) & 22% (2206 kg ha^{-1}) with CB and R&F, respectively over flat-bed (1815 kg ha^{-1}). The water use efficiency in CB increased by 13% (8.26 kg ha^{-1} mm^{-1}) and 16% with R&F (8.48 kg ha^{-1} mm^{-1}) over flatbed sowing (7.34 kg ha^{-1} mm^{-1}) indicating importance of *in-situ* rainwater conservation practices in Ballari region.

Tillage practices to reduce evaporation and weeds control: Organic surface cover reduces evaporation, soil loss and conserves rainwater *in-situ*. Even dust mulching reduces evaporation from soil surface due to reduced surface cracking at later stages of crop growth. Studies on surface mulching indicated higher *rabi* sorghum grain and straw yields by 88% and 21%, respectively while clod mulch (10 cm deep) recorded 8% higher grain yield of 1833 kg ha^{-1} over surface mulch (Average of 5 years during 1980s). In black soils of Ballari, surface (organic) mulch was highly beneficial. In its absence, dust mulching (5 to 10 cm) during cropping season conserves rainwater and increases crop yields. Across four seasons (1978-79 to 1981-82), weed control by hand *khurpi* increased yield by 112% over control. Inter-culturing with blade harrow and sweeps increased sorghum yields by 41% and 32%, respectively over control. Further, yields increased by 85% and 96%, respectively when intra-row weeding was done with *khurpi*. Hence, inter-culturing with sweeps along with intra-row hand weeding is recommended due to low operational cost.

Low tillage farming strategies for resource conservation and productivity: Conventional tiilage (CT) with recommended rate of fertilizer (RRF) and hand weeding (HW) (1694 kg ha^{-1} and 5.89 kg ha^{-1} mm^{-1}) and low tillage (LT) with application of 2 t ha^{-1} of *Leucaena* and HW (1528 kg ha^{-1} and 5.65 kg ha^{-1} mm^{-1}) recorded significantly higher winter sorghum grain yields of 83% and 66% and WUE by 48 and 42%, respectively over LT with herbicide application (930 kg ha^{-1} and 3.98 kg ha^{-1} mm^{-1}). Hence, resourceful farmers can adopt CT and resource poor farmers can adopt LT with *Leucaena* application and weed control through HW in Ballari Vertisols.

Tillage practices and integrated nutrient management (INM): During severe drought year (2002–03), when the crop experienced water stress at reproductive stages, there was no significant effect of tillage practices on *rabi* sorghum yields whereas CT (1 ploughing + 2 harrowing + 2 hoeing + 1 hand weeding) performed better with significantly greater grain yield by 15% (1876 kg ha^{-1}) over low tillage treatments, i.e., RT (1621 kg ha^{-1}) (2 harrowings + 1 hoeing + 1 hand weeding) and 20% over LT (1561 kg ha^{-1}) (1 harrowing + 1 hoeing + weedicide) during moderate drought year (2000–01) with pre-monsoon rainfall of 139.6 mm prior to sowing and 90.3 mm crop season rainfall. Higher grain yield (1791kg ha^{-1}) was observed when 50% N was supplied through an organic source and 50% through an inorganic source during a moderate drought (2000–01). During above normal rainfall year (2001–02) with sufficient rainfall (prior to sowing and during crop season), application of fertilizer through urea alone (inorganic source) recorded significantly higher grain yield (3064 kg ha^{-1}). The mean WUE was slightly higher in CT (8.98 kg ha^{-1} mm^{-1}), over RT (8.73 kg ha^{-1} mm^{-1}) and LT (8.48 kg ha^{-1} mm^{-1}). Higher sorghum grain yield (1745 kg ha^{-1}) was obtained when N was supplied through organic sources alone during 2002–03 when there was a severe drought with only 9.3 mm of crop season rainfall. The results indicated that sorghum responded to a higher rate of N application whenever there was sufficient water available in the profile and whenever there was a scarcity of water in the profile during the cropping season sorghum responded to the lower rates of N application . The mean sorghum grain yield (average of 3 years) increased by 9% (2063 kg ha^{-1}) and 12% (2120 kg ha^{-1}) with 50:50 organic:inorganic and inorganic alone, respectively over 100% organic source (1892 kg ha^{-1}). The WUE was 11% and 18% higher in organic and inorganic source and inorganic alone as compared to 100% organic sources.

Under varying rainfall situations, CT conserved more rainfall and performed relatively better than RT or LT. Sorghum response to INM varied differently under different rainfall situations in all 4 years of study. In a drought year, 50% reduced N application serves better whereas in a nearly drought year RRN is better. In a good rainfall year, 150% RRN produced a significantly greater yield . In sunflower, reduction in soil bulk density, increase in infiltration rate and porosity with higher soil water storage under CT compared to RT and LT was observed. Sunflower seed yields were 13% and 32% higher in CT compared to RT and LT, respectively. In INM treatments, higher rates of fertilizer application recorded higher soil moisture, decreased bulk density, and increased porosity and infiltration rate compared to INM_2 and INM_1. Higher soil moisture with greater nutrient availability produced 8% and 17% higher seed yield with INM_2 (100% RDN-100% urea) and INM_3 (150% RDN-150% urea) compared to INM_1 (50% RDN-50% urea). Thus, CT with INM_3 is recommended for adoption for sustaining sunflower productivity under rainfed conditions during the winter season as a climate-resilient agricultural practice in vertisols of SAT region.

Nutrient management

A study was conducted at research farm and on farmers' fields to determine the effect of N rate and sources on sorghum growth and yield during *rabi* season in the Vertisols of Ballari region. During normal and above-normal rainfall years, an increase in N application up to 40 kg ha^{-1} increased grain yield from 2128 kg ha^{-1} (control) to 2396 kg ha^{-1}. Further increase in N application was not beneficial at research farm. During the years of low rainfall, significantly higher grain yield was recorded with 20 kg N ha^{-1} over control and was on par with 40 and 60 kg N ha^{-1}. Response to added N fertilizer was low in the farmers' fields as compared to research farm and it was attributed to lower soil nutrient status for available N, P_2O_5, and K_2O. During normal to above normal years of rainfall, an increase in N application up to 60 kg ha^{-1} resulted in increased grain yields from 1613 kg ha^{-1} (control) to 1785 kg ha^{-1} in the farmers' field. During normal and below-normal rainfall years, application of calcium ammonium nitrate recorded higher grain and straw yields at both research farm and in farmers' fields. Application of 38 kg N ha^{-1} recorded a B:C ratio of 2.67:1 during normal rainfall years and optimum rate was 33 kg N ha^{-1} with a B:C ratio of Rs.1.29:1 during below normal rainfall years at the research farm. In farmers' fields, the relationship was linear with the increase in N rate during normal rainfall years and quadratic during below rainfall years. Optimum rate of 27 kg N ha^{-1} with a greater B:C ratio of 2.15 was observed during below-normal rainfall years.

Significantly higher grain yield 2629 kg ha^{-1} was recorded with application of 90 kg P_2O_5 ha^{-1} with similar trend in straw yield also at research farm during normal rainfall years**.** Increased application of P_2O_5 had no significant influence on the grain and straw yield of sorghum. However, higher grain (964 kg ha^{-1}) and straw yield (17.6 q ha^{-1}) was recorded with application of 30 kg P_2O_5 during sub–normal rainfall years at research farm. Grain and straw yields of sorghum in farmers' fields increased with increased application of P_2O_5 during normal rainfall years. Higher grain yield (1848 kg ha^{-1}) was recorded with application of 90 kg and straw yield with 60 kg P_2O_5 ha^{-1} (27.5 q ha^{-1}). Among the sources, DAP application proved more beneficial than SSP, irrespective of rainfall at research farm and in farmers' fields. During years of normal rainfall, higher grain and straw yields were recorded with DAP application, whereas, during sub–normal rainfall years yield differences due to P sources were not significant at research farm and farmers' fields. During years of normal rainfall, 53 kg P_2O_5 ha^{-1} produced higher B:C ratio of 1.77 whereas, during sub–normal rainfall years application of 26 kg $P_2O_5 ha^{-1}$ resulted in a B:C ratio of 1.17 at research farm. In farmers' fields, application of 53 kg P_2O_5 ha^{-1} was optimum during normal rainfall years and 26 kg ha^{-1} was optimum with greater B:C ratio of 2.14 during sub–normal rainfall years.

Effect of integrated nutrient management (INM) in winter sorghum and crop rotation with chickpea either over the years or in strips over 8 years of the study indicated that the response to different INM treatments was higher in winter sorghum, followed by chickpea and sorghum + chickpea in strips. The average (8 years) winter sorghum yield response indicated that the treatment with 15 kg N through *Leucaena* loppings+20 kg N through urea (T_8) produced higher sorghum grain equivalent (SGE) by 56% over control followed by 51% increase in SGE with application of 100% recommended rate of N through urea (T_2). In the years of drought, application of N through 15 kg N through compost +10 kg N through *Leucaena* loppings (T_9) increased the sorghum grain and straw yields over other treatments, whereas in the normal and above normal rainfall years application of N either with 15 kg N through *Leucaena* loppings + 20 kg N through urea (T_8; 100% RRN through urea) (T_2) proved better.

In the chickpea block, treatment T_8 produced 62% higher SGE over control followed by 53% increase in SGE with application N through 15 kg N through compost+10 kg N through *Leucaena* loppings (T_9). In the years of normal and above normal rainfall chickpea yields were higher when sorghum was applied with 15 kg N through *Leucaena* loppings+20 kg N through urea whereas during drought years chickpea yields were higher when sorghum was supplemented with organic amendments through compost/ *Leucaena* loppings in previous season. In sorghum+chickpea in strips, the treatment T_8 produced 44% higher SGE over control followed by 38% increase in SGE with application N through 15 kg N through compost+10 kg N through *Leucaena* loppings (T_9) when sorghum and chickpea were cultivated in strips and yields of sorghum and chickpea were converted into SGE.

Terrace-level resource conservation measures: Graded bunds of 0.6 m^2 cross-section at vertical intervals ranging from 0.75 to 1.25 m were demonstrated at the G.R. Halli watershed during 1980-1994, the Chinnatekur watershed in Kurnool district during 1986-1994, and Joladarasi watershed in Ballari district during 1987-1994 for resource conservation and to improve crop yields. At Chinnatekur, the runoff from arable areas got reduced to around 5% when compared to 9% under control with 70% reduction in soil loss. Across seasons and years, graded bunding increased yields ranging from 13 to 21% in different crops. In an evaluation of farmers' perception, 82% of the respondents expressed problems with contour bunding as they breach and cause water stagnation and loss of area, while in case of graded bunds 66% of the farmers expressed lack of awareness as well as non-availability of technical guidance, while 6% expressed lack of conviction.

Inter-terrace level resource conservation measures: Terrace level measures could not conserve rainwater, as the lands are slopy with undulations resulting in un-uniform soil wetting in farmers fields. Thus for uniform soil wetting and to break the slope and reduce velocity of runoff and increase opportunity time for rainwater to soak into the soil profile, the *in-situ* rainwater conservation practices like land smoothening, contour cultivation, compartmental bunding, contour borders, ridges & furrows and dead furrows were demonstrated on the farmers' fields across seasons and locations. Adopting *in-situ* rainwater conservation measures reflected in increase in crop yields ranging from 7.7 to 114%. Contour cultivation improved sorghum yields by 14% over control. Adoption of compartmental bunding resulted in 20 to 25% increase in groundnut and sorghum yields. Similarly, land smoothing in the inter-terraced area brought about 16% increases in yield. Developing the land into border strips brought additional yields of 19 to 114% in sorghum depending on seasonal conditions and 22% in groundnut. Vertical mulches brought an additional grain yield of 41% depending upon the location and seasonal conditions. The above measures are complementary to each other and were found to be cost-effective, with a payback period of 1 to 2 years except border strips which required 5 to 7 years depending upon the value of the produce.

Land use planning

The performance of crops, many a time is poor due to limitations of slope, depth, salinity, etc. Soils in the semi-arid region vary considerably with respect to their physical and chemical characteristics in a catena. The demonstrations of suitability of crops for different depths in red soils of farmers at G.R. Halli watershed indicated that even under irrigation conditions at given level of input use, the sorghum yields were higher by 46% when the soil depth increased from 22.5 cm 45 cm and above. Under similar rainfall conditions, sorghum yields were 71% higher whereas ragi yields increased by 10% with increase in soil depth from <22.5 cm to 45.0 cm thus indicating that ragi is less sensitive to changes in soil depth. These results indicate that cultivation of crops in relation to soil depth stabilizes yields in irrigated and rainfed conditions.

Land use planning in relation to land capability class (LCC) helps to prevent further degradation, improves income and brings about economic stability. The class V to class VIII lands not fit for agriculture account for 11 to 51% land area across watersheds located in the SAT region. Alternative land use was demonstrated on fields of ten of class VI lands at G.R. Halli watershed, Karnataka. Since the area was unfit for cultivation, the land was bunded to prevent erosion, a few farmers were permitted to grow crops and the remaining were made to grow woodlots with *Eucalyptus* trees. At the end of 5 years, the B:C ratio for the woodlots was 3.67 while it was only 2.93 for crops. In another case at Chinnatekur watershed, Kurnool district, Andhra Pradesh, by protecting such lands from biotic interference, the grass yields improved from 2.6 to 11.6 t ha^{-1}. With application of 20 kg DAP ha^{-1} the yields increased to 17.7 t ha^{-1}. Further, with introduction of legumes like *Stylosanthes hamata*, the yields increased further to 27.3 t ha^{-1}.

In marginal lands, having the facility of protective irrigation, shifting to agri-horti system in Vertisols of Joladarasi, Ballari district, Karnataka, yielded 6 times more net returns with 3 to 4 times more employment on a continuous basis compared to cultivation of sorghum with protective irrigation. In sandy river beds with trees planting at Chinnatekur watershed, A.P, the productivity was 10 t ha^{-1} yr^{-1} after 10 years of plantation. However, when this land was cultivated with jasmine/guava, net returns per hectare stabilized at Rs. 24,863 for jasmine and Rs. 22,320 for guava. It is clear that land use planning according to capability and use of alternatives is required for realizing higher production capabilities.

Intercropping of coriander+safflower recorded 97% more net returns compared to mixed cropping of coriander and safflower in black soils of Joladarasi watershed. Setaria + redgram cropping system recorded 61% additional net returns over setaria in Vertisols and groundnut + redgram in red soils recorded 10% more net returns compared to pure crop of groundnut of Chinnatekur watershed.

Among the cereal crops, *kharif* sorghum, ragi, bajra and setaria in red and medium black soils and *rabi* sorghum were evaluated. *Kharif sorghum,* across seasons, recorded nearly two-fold higher grain yields under improved practice when compared to farmers' practice at G.R. Halli, Hadagali and Chinnatekur watershed. The demonstrations on improved method of cultivation in oilseeds such as groundnut, safflower, sunflower and castor revealed production increases of 29, 182, 55 and 155%, respectively over farmers' practices. In the improved technology of pulses demonstrations, chickpea recorded on an average, across seasons 451 kg ha^{-1} as against 190 kg ha^{-1} under farmers' practice at Hadagali and 1020 kg ha^{-1} at Chinnatekur watershed due to favorable seasonal conditions. Redgram registered yield increases to the tune of 418 kg ha^{-1} as against 298 kg ha^{-1} under farmers' practice at Chinnatekur watershed.

Risk minimization

Dryland agriculture in SAT black soil region experiences 5 droughts of different intensities in a normal decade. Rainfed *rabi* cropping success depends upon the moisture stored in the soil profile at sowing in September and on the receipt of October rains. Hence, harvesting excess runoff and recycling as a protective irrigation enhanced 30-85% crop yields and net returns from 33% to 125% in the region. Based on advance prediction of October rains (good or bad) contingent plans to make correction in crops grown on recommended practices were developed by introducing population corrections in the standing crop to reduce risks and stabilize yields. Compartmental bunding (CB) with cultivation of BGD 103 and JG 11 chickpea varieties in Vertisols at Ballari, increased the grain yields from 13 to 16%, respectively. Similarly, demonstration cum field evaluation of chickpea variety JG 11 in Joladarasi, K. Veerapur and Chellagurki villages of Ballari district indicated that higher chickpea yields, profit and energy gains can be achieved by cultivating JG 11 variety with micronutrients application at 5 kg ha^{-1} in Vertisols of Ballari region during winter season.

Way Forward

According to the prevailing farming situations, climatic regimes and biophysical endowments of the farming community in the region, the Ballari Centre has conducted need-based research to address the issues related to the production agronomy, *in-situ* and *ex-situ* soil and water conservation measures and varietal trials with varied crop combinations. The Centre has developed and promoted various *in situ* moisture conservation techniques, tillage practices, crops, and varieties along with integrated nutrient management for sustainable agricultural production in the domain region. Evaluated and proven dryland technologies were demonstrated in various watershed developmental projects in the region. The contemporary knowledge of the climatic situation and their predictability and improved and efficient water application techniques are prompting the Centre to continue its collaboration with AICRPDA for the evaluation of future technologies to meet the demands of unforeseen climatic situations and national targets such as doubling the farmers' income in the dryland regions through the dissemination of cost-effective technologies in crop production.