Indian J. Dryland Agric. Res. & Dev. 2022 37(2): 51-59 10.5958/2231-6701.2022.00017.3

Overview of Dryland Agriculture Research and Achievements in Northern Dry Zone of Karnataka

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Brief history of the centre

A dry farming research centre was started at Bijapur in 1933. Later on, a sub centre of All India Coordinated Research Project for Dryland Agriculture was started at Bijapur in 1970. Subsequently the Sub-centre was upgraded as Main centre in 1984. This centre was under University of Agricultural Sciences, Bangalore up to 30th September 1986 and from 01-10-1986 repatriated to University of Agricultural Sciences, Dharwad. Presently, the centre is located at Regional Agricultural Research Station, Vijayapura (earlier Bijapur) in Karnataka.

Agro-climatic zone characteristics

The agroclimatic zone of the centre is the Northern Dry zone (Zone-3) of Karnataka. This zone covers an area of 4.78 million ha of Vijayapura, Bagalkote, Gadag, Bellary, Koppal, parts of Dharwad, Belagavi and Raichur. Northern Dryzone of Karnataka (Zone-3) and it comprises five Agro-ecological sub regions such as; Hot Arid ESR (24, 28 200 ha), 6.1 Hot dry semi-arid ESR (13, 88 408ha), 6.2 Hot moist Semi-arid ESR (60,000 ha), 6.4 Hot dry sub-humid ESR (9,12,000 ha) and 7.1 Hot dry Semi-arid ESR (64, 200 ha). The climate in this zone is dry semi-arid. Out of the total annual average rainfall of 594.4 mm with 38 rainy days, the South-West monsoon contributes 65%, while 22.5% and 12.5% is from North-East monsoon and summer, respectively. The normal onset of South-West monsoon is during the first week of June and normal withdrawal is during the first week of September. Maximum normal air temperature ranging from 38.6 to 39.15 °C was noticed in April and May. The mean monthly minimum temperature of 14.55°C was noticed in January. Higher wind speed was observed in June and July and less wind speed in November. The relative humidity during the period fluctuated between 31.1% in March to 69.9% during August.

Major soil types

The major soil types in the zone are shallow to very shallow black soils (43%), medium deep to deep black soils (37%) and fine red clay loam/ red and black mixed soils (20%).

Mean season-wise and annual rainfall and rainy days at AICRPDA Centre, Vijayapur

Rainfall	Normal rainfall (mm)	Normal rainy days (No.)
South west monsoon (June-September)	387.5	24
North east monsoon (October-December)	134.0	9
Winter (January - February)	6.8	-
Summer (March-May)	66.1	5
Annual	594.4	38

Major rainfed crops

The major rainfed crops cultivated in the zone during *kharif* are pigeonpea, green gram, pearl millet and sunflower; during *rabi* are chickpea, *rabi* sorghum and safflower.

Dryland agriculture problems

Crop production related constraints

- Inadequate, low and erratic rainfall, most vulnerable and aberrant weather condition, undulating topography and rolling plains and lowering of groundwater table
- Low adoption of rainwater management techniques with special reference to moisture conservation practices and low adoptability of farm ponds at farmer's level
- Soils are highly degraded with low water retention capacity, multiple nutrient deficiencies and low organic content (0.35 to 0.50%), very low or negligible use of organic manures, risk of crop failure, monocropping and low yielding crop varieties

Infrastructure and institutional constraints

- Physical constraints of transportation which link the farmers with different profiles of market and also facilities of cold storage and power are existing
- Fragmentations of small holdings have constraints for efficient use of land, family labour and cannot reap scale economics

Socio-economic constraints

- Migration of agricultural labourers
- Small and marginal farmers do not have the ability to invest in agriculture and allied sectors requiring high capital and labour inputs
- Market risks

Research initiatives/focus since inception of the centre

To address the above constraints, various research programmes were formulated and submitted to the different externally funding agencies for the funding and implemented the same on station and on farm.

NWDPRA - Operational Research Project: During the year 1993, under the National Watershed Development Programme for the Rainfed Agriculture (NWDPRA), the University of Agricultural Sciences, Dharwad had been assigned the responsibility of conducting the adoptive research on rainwater conservation and sustainable agricultural production system. In turn, the University assigned a major part of this activity to the dryland Centre, Vijayapura. This project was operational from 1993-2003 (10 years). Under the project, eleven model micro watersheds one micro watershed in each of the districts on a holistic approach in Northern Karnataka have been developed.

National Innovations on Climate Resilient Agriculture (NICRA): Since 2011, the NICRA project has been operated at Vijayapura centre. The village, Kavalagi has been selected for the study. The centre initiated the both on station and on farm research/demonstrations on real–time contingency measures. The contingency measures includes both addressing the real time issues as well as the preparedness.

Advanced research and upscaling of dryland technologies in Northern Dry zone of Karnataka (DARE-GoI): Under the DARE, GoI, SFC funded project, during 2013-15, three villages Honwad, Hansbhavi and Hullur villages were selected from the Vijayapura, Bagalakote and Gadag districts respectively. SWC structures (bunds, farm ponds) were constructed in 1,000 ha area of project villages and also other dry land practices were demonstrated. About 15-20% increase in yield was observed in treated areas over the conventional practices.

CGIAR-DS Upscaling of focused dryland technologies through participatory mode: UASD and ICRISAT collaborative research project CRP-DS (CGIAR Research Program on dryland systems) was operated under AICRPDA (UAS Dharwad, Karnataka) at Vijayapura center from 2014-2016 (two years) with the main objective of transferring dryland technologies to the farmers for climate-resilient agriculture. In this project, three villages *viz.,* Nandihal, Manur and Balaganur of Vijayapura dist. were selected for conducting demonstrations, research activities and capacity building.

CGWB - Rainwater harvesting and ground water recharge in Vijayapura campus: The CGWB funded project was implemented during 2012-14 at RARS, Vijayapura campus. The economics of the project revealed that the cost of rooftop rainwater harvesting works out to be Rs. 19.20 per 1000 litres of water. The cost of water harvesting through the artificial recharge structure is about Rs. 3.64 per 1000 litres of water. The weighted average of the unit cost of water harvesting of all the structures would be Rs. 4.35 per 1000 litres.

IWMP - Installation of silt monitoring stations for runoff and sediment studies*:* The University of Agricultural Sciences, Dharwad collaborated with the watershed development department from 2011-2014 in establishing and monitoring silt monitoring stations (SMS) at the selected micro watersheds in the districts of Vijayapura, Bagalakote, Gadag, Dharwad, Belagavi, and Uttara Kannada. These districts fall in three agro-climatic zones viz., northern dry zone, hilly zone, and northern transition zone. The benchmark information (pre-treatment) on runoff, soil loss and nutrient loss were monitored. Further, change in the runoff, soil loss and nutrient losses after the imposition of the soil and water conservation measures in the watershed were also monitored.

Significant achievements/findings

Rainwater management

- Impact evaluation of inorganic mulches on the major crops of this region indicated that in the mulched plots, additional yield advantage of 11.28-62.8 percent was recorded over the control, while the average reductions in the runoff and soil loss over the control were 31 and 52 percent respectively.
- In set-furrow cultivation, pigeonpea equivalent yield was significantly higher in set furrow with residue + glyricidia incorporation (1409 Rs. ha^{-1}). But it was on par with set furrow with silt + residue + glyricidia incorporation (1349 Rs. ha^{-1}).
- Compartmental bunds help in conserving soil moisture and the rainwater is conserved in the bunds where it falls as the bunds provide more opportunity time for water to infiltrate into the soil. Adoption of compartmental bunding in *rabi* sorghum, sunflower, safflower and chickpea gave yield advantages of 40, 35, 38 and 50%, respectively over no compartmental bunding or flat planting.
- Wider row spacing with frequent deep inter-cultivation with blade harrow increased the yield of pearl millet to 500 kg ha^{-1} as against 250 kg ha^{-1} with farmers practice. The effectiveness of this technology was more observed during sub normal rainfall years. Response of *rabi* sorghum with recommended practices to contour key line cultivation in shallow black soil was conducted at Vijayapura centre.

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- Sowing of *rabi* sorghum along the contour key line with 60 cm row spacing and recommended dose of fertilizer gave a higher yield of 8.0 q ha^{-1} compared to 5.0 q ha^{-1} when sowing was done along the slope as per farmer's practice.
- Double cropping was made possible due to this Zingg Conservation bench terraces in the farmers' fields. The extent of increase in the yield of different crops ranged between 30 to 60%.
- Studies on vegetative and mechanical checks for soil and moisture conservation revealed that the runoff reduction due to the vegetative and mechanical checks as against the control plot was in the range of 20.2 % to 47.8%.
- Sub soiling (chisel plough) is one of the cheap and effective *in-situ* moisture conservation measures. From the three years study, it is concluded that the subsoiling at 2 m spacing with vermicompost application @ 2.5 t ha^{-1} has recorded the higher yield of 25.3%. The higher yield is attributed to the sub soiling, which helped higher infiltration of rainwater into the soil.
- Pebble mulch recorded lower runoff (11 ha cm) compared to conventional practice (38 ha cm), resulting in a lesser quantity of soil loss of 0.78 t ha^{-1} as against 4.51 t ha^{-1}, and produced greater wetting front depth. Further, it gave a higher sorghum grain equivalent yield of 24.5 q ha^{-1} compared to 16.5 q ha^{-1} with conventional practice.
- The surplus water calculation under GIS environment showed that the annual runoff as the percentage rainfall was 14.38 percent (81.6 mm).The analysis of rainfall intensity of eight rain gauge stations of 11 years (2001 to 2011) period revealed that most of the time i.e., six out of ten times the maximum rainfall intensity was occurred during September followed by May and October, hence chances of filling up of the rain water harvesting structures are very high during these months. Based on rainfall, topography of the land, soil type and land use pattern, a farm pond of 150 m^3 size is sufficient for each hectare of catchment area in black soils with provision of emptying it after its fill-up to accommodate the subsequent events of runoff. Farm pond water balance revealed that 625.7 m^3 (27.3%) of water was lost in the form of evaporation from June to January, 200 m^3 (8.6%) water was lost in the form of seepage and about 6 per cent water was left in the pond as the dead storage, resulting in the remaining 1328 m^3 (58 %) of water for use. The evaporation of water was quantified during 2016 and 2017. During this period, it was observed that least evaporation was recorded in steryl alcohol (106.9 cm) followed by silicon oil (107.5cm). The highest evaporation was observed in control (181.07 cm). This water could be beneficially used by providing one supplementary irrigation of 50 mm to obtain additional yield of 39.7% in sorghum and 29.2% in chickpea.
- Groundwater recharge by diverting nala water through a horizontal filter to an open well indicated the possibility of harvesting annually 4.14 lakh litres of the runoff water. The hydro geologically nine significant different thematic layers viz., geology, soil, land use/cover, water table fluctuation, depth to bed rock, slope, drainage density, lineament density and geomorphology were used as the input and multi criteria evaluation (MCE) for finalizing/ recharge suitability sites for the upper Don river basin. For arresting the silt in ground water recharge, the vertical filter performed better than the horizontal filter. Further, wherever only sand is available, then 60 cm thick sand filter may be used, it works with the 78 per cent efficiency. Further, where all the three layers (sand + medium jelly + small boulder) are available then filter with the nylon mesh should be used. With this, the highest filter efficiency of 94 percent could be achieved. The impact analysis of SWC works on groundwater recharge revealed that the shallow water table was recorded during October, while the deep was recorded during June, further the average ground water recharge recorded was 9.9 - 11.5 percent of annual rainfall, similar recharge results were reported by National Institute of Hydrology. Further, the SWC structures were effective for recharging, only when annual rainfall was normal or above normal. The impact of RWH structures on depth to the water table, water yield and water quality of seven observation bore wells, which are falling in the vicinity of the RWH structures were selected. The year 2012-2013 was treated as pre-treatment year and the years 2013-14 and 2014-2015 were treated as post-treatment years. The outcomes of the monitoring of the observation wells revealed that there was the trend of increase in the water table and the well yield.
- The crop management factor 'C' values for USLE soil loss assessment model were determined as 0.5 for *kharif*, 0.7 for *rabi*, and 0.3 for the bi-seasonal crops. Established the silt monitoring stations (SMS) at the selected micro watersheds in the districts of Vijayapura, Bagalakote, Gadag, Dharwad, Belagavi, and Uttara Kannada. The benchmark information (pre-treatment) on runoff, soil loss, and nutrient losses were monitored. Further, change in the runoff, soil loss and nutrient losses after the imposition of the soil and water conservation measures in the watershed were also monitored.

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Crops and cropping systems

- Residue incorporation alone and residue incorporation + tied ridging gave significantly higher yield of pigeonpea, *rabi* sorghum and chickpea as compared to control. This is attributed to higher available moisture content and conspicuous increase in the physical and biological properties of the soil. For sustained higher yield there is no need to apply nitrogen to *rabi* sorghum + chickpea intercropping system in the yearly rotational cropping system of pigeonpea-sunhemp - *rabi* sorghum + chickpea (2:1) if crop residues (only leaf litter plus roots of pigeonpea) are incorporated continuously. Tied ridging is an additional advantage especially during low rainfall years. In another study to determine the best genotype with the land configuration for exploiting higher yield potential of pigeonpea under rainfed condition, the pigeonpea GRG-152 produced higher seed yield than TS-3R. In land configuration treatments, planting pigeonpea on broad bed furrow recorded higher yield over flatbed.
- Intercropping of castor + sunflower in the row ratio of 2:4 or 1:1 gave significantly higher net returns compared to sole crops and other intercropping systems. Net returns of Rs. 14731 ha^{-1} in castor + sunflower (2:4), Rs. 55378 per ha with incorporation of crop residue and 1 t ha^{-1} of poultry in chilli + onion (2:4) were found significantly superior compared to traditional cropping systems. *Rabi* sorghum grain equivalent yield in *rabi* sorghum + chickpea intercropping system was significantly higher when it was followed by *kharif* sunflower with 135 cm x 30 cm planting geometry.
- Among different ITK cropping systems which are rotated with pigeonpea + greengram (2:4), onion relayed with *rabi* sorghum rotated with pigeonpea + greengram (2:4) produced significantly higher pigeonpea equivalent yield (3751 kg ha^{-1}), gross returns (Rs. 77670 ha^{-1}) and net returns (Rs. 52961 ha^{-1}). In chilli + onion (2:4), spraying of cow-pat pit manure (5g/litre), (Rs. 33433 ha^{-1}) bio-digestor (Rs. 31258 ha^{-1}) and vermiwash (1:5), (Rs. 30434) spray found to record significantly higher net returns. Studies on alternate cropping systems and new crop introductions in medium to deep black soil shows that, Chilli + Onion (2:4) cropping system with poultry manure application (2 t ha^{-1}) incorporation of crop residue resulted in significantly higher net returns compared to other cropping systems.
- Among production systems followed by different farmers, cucumber–sunflower production system gave the highest B:C ratio followed by the cucumber – *rabi* sorghum. These practices during *kharif* provide substantial income to the rainfed farmers besides reducing the rain drop impact on the soil and conserving the rainwater *in-situ.* Growing of cucumber, ridgegourd, bittergourd during *kharif* ensured substantial additional income to the farmers and efficient *in-situ* rain water harvesting.
- Growing of Bt. Cotton at 120 cm x 45 cm with application of 60:30:60 kg NPK per ha produced significantly higher kapas yield, gross returns and net returns (1433 kg ha^{-1}, Rs. 70,037 ha^{-1}, Rs. 46115 ha^{-1}). In onion, crop geometry of 45 cm x 10 cm with application of 62.5:25:62.5 kg N, P_2O_5, K_2O per ha gave significantly higher bulb yield of 7930 kg per ha. Moth bean genotype MBS-27 spaced at 45 cm x 10 cm with application of vermicompost @ 1 t ha^{-1} produced higher seed yield, gross returns and net returns. Chickpea variety GBM-2 and JG 11 at 45 cm x 10 cm gave significantly higher seed yield. Similarly black gram at crop geometry of 45 cm x 10 cm with application of 15:37.5 kg N, P2O5 per ha gave significantly higher grain yield of 595 kg per ha. Clusterbean (gum gaur) sown at crop geometry of 30 cm x 10 cm gave significantly higher grain yield of 408 kg per ha as compared to 45 cm x 15 cm (361 kg ha^{-1}), 45 cm x 20 cm (293 kg ha^{-1}), 60 cm x 10 cm (275 kg ha^{-1}) and 60 cm x 20 cm (229 kg ha^{-1}). But it was on par with 45 cm x 10 cm (401 kg ha^{-1}). Response of mustard genotypes to dates of sowing under supplemental irrigation indicated that, sowing of mustard variety SEJ-2 during Sept II fortnight with two protective irrigations gave significantly higher yield compared to other varieties. Sowing of mustard (SEJ-2) during Sept II fortnight is best suited for this area under supplemental irrigation.
- There was no significant difference in the grain and fodder yield of *rabi* sorghum due to hydrogel. Studies on drought proofing technologies in *rabi* sorghum and chickpea revealed that, in *rabi* sorghum the grain yield was significantly higher with seed treatment of cow urine for 8 hours whereas seed soaking in water, cow urine, panchaganga for 8 hours and seed treatment with KH_2PO_4 gave significantly higher seed yield of chickpea compared to control. Seed treatment with cow urine for 8 hours in sorghum and soaking of chickpea seeds in water are the promising cheaper non cash techniques of drought proofing. In real-time monitoring and management of agricultural drought in pigeonpea indicated that the treatment, including real-time contingency plan interventions during early, mid-season, and terminal drought, recorded 11.83% higher yield and 14.34% higher net returns than farmers' practice (no interventions) treatment.
- In contingent crop planning, the performance of different cropping systems in different 'Nakshatras' were studied and the suitable cropping systems to different nakshatras at different soil types were developed.

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- Based on the soil conservation unit (SCU) and soil quality units (SQU), the land management units (LMU) have been derived at Kavalagi watershed area. There is a total of 14 LMUs. However, for the study, four LMU (I, III, V and VII) have been considered. The study was planned to observe the effects of NPK fertilizer on growth, yield and quality of chickpea under different land management units (LMU's). The LMU 1 has given significantly higher seed yield of chickpea as compared to LMU 3, LMU5, and LMU7. Among the nutrient management, the application of 37.5:75:0 NPK kg ha^{-1} has produced significantly higher seed yield of chickpea as compared to the application of 25:50:0 NPK kg ha^{-1} and farmers' practice (25:35:0 NPK kg ha^{-1}). Among the interactions, LMU 1 with the application of 37.5:75:0 NPK kg ha^{-1} has produced significantly higher chickpea seed yield as compared to other treatment combinations, but it was on par with LMU 3 with the application of 37.5:75:0 NPK kg ha^{-1}.

Nutrient management

- In permanent manurial trial on safflower - *rabi* sorghum rotation (1986-87 to 2007-08), the pooled data on seed yield of sunflower indicated that incorporation of sunhemp at 45 DAS increased the seed yield of sunflower significantly (716 kg ha^{-1}) compared to conventional practice (554 kg ha^{-1}). A permanent manurial trial on yearly rotation of *rabi* sorghum + chickpea (2:4) and safflower + chickpea (2:4) (2017-18 to onwards) indicated that application of 50% N through FYM + 50% N through inorganic sources recorded significantly higher sorghum equivalent yield and safflower equivalent yield as well as B:C ratio in *rabi* sorghum + chickpea (2:4) and safflower + chickpea (2:4) intercropping system. Low till farming strategies for resource conservation and soil quality for sorghum-sunflower yearly rotational system (2000-01 to onwards) showed higher grain yield of *rabi* sorghum (1398.5 kg ha^{-1}) was obtained with low till (LT2): 1 harrowing + 1 hoeing + weedicide and statistically on par with low till (LT1): 2 harrowing + 1 hoeing + 1 hand weeding and conventional tillage (CT). Among the nutrient management practices, the higher grain yield and monetary net returns were recorded in sunhemp incorporation @ 2.5 t ha^{-1} + 50% RDF through fertilizer. Effect on soil productivity by application and utilization of distillery by-products as organic manures in dryland regions of northern Karnataka (2020-21 to onwards) indicated highest grain yield (1830.3 kg ha^{-1}) and B:C ratio (3.9) was observed when spent wash at 5 ml kg^{-1} of soil (1:10 spentwash and water dilution) applied in conjunction with recommended dose of NP fertilizers and the same on par with the application of spentwash at 5 ml kg^{-1} of soil (1:10 spentwash and water dilution) alone.

- Integrated nutrient management in sunflower – *rabi* sorghum cropping system in medium deep black soils (1998-99 to 2002-03) showed that sunflower seed yield revealed that incorporation of sunhemp at 45 DAS increased the seed yield of sunflower significantly (1476 kg ha^{-1}) as compared to farmer's practice (882 kg ha^{-1}) and retention of stubbles on soil surface (1180 kg ha^{-1}), but it was on par with application of FYM @ 5t ha^{-1} (1333 kg ha^{-1}). The pooled data of grain yield of *rabi* sorghum revealed that application of FYM @ 5t ha^{-1} gave significantly higher grain yield of 1643 kg per ha as compared to farmer's practice (1143 kg ha^{-1}). Integrated nutrient supply system for rainfed semi-arid tropics-cereals (1998-99 to 2006-07) indicated that application of 15 kg N through compost + 20 kg N through fertilizer recorded significantly higher sorghum grain yield followed by 15 kg N through sunnhemp + 20 kg N through fertilizer. Integrated nutrient supply system for rainfed semi-arid tropics – legume (1998-99 to 2006-07) showed that the grain yield of *rabi* sorghum was significantly higher with supply of 15 kg N through sunnhemp/compost + 20 kg N through fertilizer which was comparable with application of 15 kg N through sunnhemp/compost + 10 kg N through fertilizer. Similarly, integrated nutrient supply system for rainfed semi-arid tropics: cereal + legume (1998-99 to 2006-07) proved that the grain yield of *rabi* sorghum was significantly higher with application of 15 kg N through sunnhemp/compost + 20 kg N through fertilizer and that of chickpea with supply of 15 kg N through sunnhemp/ compost + 20 kg N through fertilizer which was comparable with application of 15 kg N through sunnhemp/compost + 10 kg N through fertilizer. The response of sunflower to the applied potassium (2006-07 to 2007-08) showed the yield of crops were significantly higher with application RDF in conjunction plus organics (RD FYM) as compared to rest of the treatment. In Rainfed area network project on balanced nutrition in *rabi* sorghum (2007-08 to 2014-15), the highest grain yield of *rab*i sorghum was reported with recommended dose of fertilizer plus Zn (10 Kg ha^{-1}) plus Fe (50 Kg ha^{-1}) (1778 kg ha^{-1}) as compared to other treatments. The lowest yield was recorded in control (No manure/ No fertilizer) (1107 kg ha^{-1}). The response of chickpea and *rabi* sorghum to zinc and iron nutrition (2015-16 to 2016-17) reported significant increase in the yield of chickpea and *rabi* sorghum with the application of RDF with 10 kg each of Ferrous sulphate ($FeSO_{4.}$ $7H_2O$) and Zinc Sulphate ($ZnSO_4{\cdot}7H_2O$). Studies on foliar spray of nutrients on growth and yield of *rabi* sorghum (2015-16 to 2016-17) indicated that the yield of *rabi* sorghum was higher in foliar spray with potassium nitrate (0.5%) at 30 and 60 DAS.

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Energy management

- Sowing of sunflower with ridger-seed-fertilizer drill produced 22-57 per cent higher yield than sowing with tractor drawn seed drill. While sowing of *rabi* sorghum with bullock drawn seed drill gave 43 per cent higher yield than ridger - fertilizer - seed drill. *In situ* incorporation of sunhemp (5 t ha^{-1}) at 45-50 DAS with farmers method of nutrition under conventional tillage was found to be significantly superior for both *rabi* sorghum and sunflower in yearly rotation cropping system. Among the different automatic seed drills, CRIDA bullock drawn automatic seed drill performed better, the experimental data revealed that in chickpea, sorghum and greengram crops, an additional yield of 14.5, 12.25 and 20.79% was recorded over the conventional seed drill respectively. The higher yield is attributed to uniform seed spacing and placement. 50% of labour could be saved over the conventional seed drill. Evaluation of lifting devices for farm pond revealed that CRIDA recommended 2 HP, low head and high-speed petrol start diesel run engine and 1KW capacity solar surface pump can be successfully used to lift the farm pond water to irrigate the field by six sprinkler heads. Adoption of mechanization in the cultivation of pigeonpea was found more profitable and energy efficient. The net returns and benefit cost ratio was higher as compared to the farmer's practice because of the precise use of inputs such as seeds, fertilizers, chemicals, etc. Timely completion of various field operations reduces the crop damage or infections due to weeding, insects and pest attack, etc. About 20 to 25% of farm income can be increased by the reducing input cost through mechanization. Dryland agriculture centre, Vijayapura has developed automatic compartmental bund former, from which per day 6 ha area could be covered. The cost of the compartmental bunding was Rs.450 ha^{-1}. The sub soiler is used to puncture the hard pan, so that it facilitates the infiltration and thus enhances the soil moisture.

Alternate land use systems

- In tamarind based horti-pasture system, the fruit yield of tamarind was significantly higher with the geometry of 10 m x 6 m (678 kg ha^{-1}) than 10 m x 3 m (493 kg ha^{-1}) and 10 m x 9 m (356 kg ha^{-1}). The planting of tamarind in crop geometry of 10 m x 6 m with guinea grass recorded maximum system productivity as tamarind equivalent yield (759 kg ha) and net returns (Rs. 70,750 ha^{-1}) and it is best suitable for shallow black soil/eroded soils.
- In aonla based agri-horti systems, the arable crops like chickpea and safflower + chickpea were grown between horticulture crops like aonla + henna, aonla + custard apple, aonla + custard apple+ henna and aonla alone in medium black soils. Growing chickpea + safflower intercropping in aonla + custard apple + henna system is the best practice for higher system productivity and profitability in medium black soils.
- In sapota based agri-horti system, sapota + guava, sapota + drumstick and sapota alone were grown in the main plot and guava, drumstick and no intercrop in the subplot and chickpea were sown in between horticulture crops as an intercrop. The system of sapota + guava with drumstick and chickpea as intercrop is the best system for realizing higher system productivity and profitability, and the sunflower – *rabi* sorghum + chickpea (2:1) sequence cropping system in sapota plantation found to be profitable and drought proofing technique in medium black soils.
- In the simarouba-based agri-horti system, simarouba + guava, simarouba + drumstick and simarouba alone grown in the main plot and guava, drumstick and no intercrop in the subplot and chickpea were sown in between horticulture crops as an intercrop. Among the main plots, significantly higher chickpea equivalent yield, gross returns and net returns were obtained with the plantation of simarouba + guava compared to other horticulture components. The system of simarouba + guava with drumstick and chickpea as an intercrop is the best system in medium black soil for realizing higher system productivity (1739 kg ha^{-1} in chickpea equivalent yield) and profitability (Rs.61295 ha^{-1}).

Technologies developed

Rainwater management

- Compartmental bunding in black soils
- Ridges and furrows for *in-situ* moisture conservation
- Tied ridges in black soils
- Set furrow cultivation
- Cover crops in black soils
- Retention of crop residues on the soil surface
- Wider row spacing with frequent deep inter-cultivation
- Graded border strips for medium to deep black soils
- Zingg conservation bench terraces in medium to deep black soils
- Inter plot rain water harvesting technique
- Farmpond for rainwater harvesting in black soils
- Ground water recharging through defunct dug wells
- Filters for recharging open wells

Crop and Cropping Systems

- Growing of moth bean in shallow black soils under dryland situations
- Dry seeding in black soils

- Priming of *rabi* sorghum and chickpea for increasing the germination and better crop establishment

Intercropping systems

- Pearl millet + pigeonpea (2:1)
- Pigeonpea + bunch groundnut (4:2)
- Pearl millet + castor (2:1)
- Pearl millet + bunch groundnut (4:2)
- Safflower + chickpea (2:4 or 1:3)
- *Rabi* sorghum + chickpea (2:1)
- Foxtail millet + niger (2:4)

Double/triple cropping systems

- Green gram – sunflower
- Green gram – *rabi* sorghum
- Green gram – chickpea
- Green gram – safflower
- Onion - *rabi* sorghum
- Onion - chickpea
- Cucumber – sunflower
- Cucumber – *rabi* sorghum
- Cucumber – chickpea

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Nutrient Management

Integrated nutrient management practices

Green gram	FYM @ 5 t, 12.5:25 kg N and P_2O_5 ha^{-1}, seed treatment with *Rhizobium* 500 g and PSB 1250 g ha^{-1}
Pearl millet	FYM @ 2.5 t , 50:25 kg N and P_2O_5 ha^{-1}, seed treatment with *Azospirillum* @ 500 g and PSB @ 375 g ha^{-1}
Sunflower	FYM @ 8 t, 35:50:35 kg N, P_2O_5 and K_2O, $ZnSO_4$ @ 10 kg ha^{-1} seed treatment with *Azospirillum* 500 g, $CaCl_2$ 2%, Borax foliar spray 0.5% and
Pigeonpea	FYM @ 6 t, 25:50:125 kg N, P_2O_5 and K_2O (for red soils), Gypsum 100 kg, $ZnSO_4$ @ 15kg ha^{-1}, seed treatment with Rhizobium 500 g, PSB 500 g, PGPR 500 g, $CaCl_2$ 2% and
Rabi sorghum	FYM @ 6 t, 25:50:125 kg N, P_2O_5 and K_2O (for red soils), Gypsum 100 kg, $ZnSO_4$ @ 15 kg ha^{-1}, seed treatment with *Rhizobium* 500 g, PSB 500 g, PGPR 500 g, $CaCl_2$ 2%
Chickpea	10:25 kg N, P_2O_5, $ZnSO_4$ and $FeSO_4$ @ 10 kg ha^{-1}, seed treatment with $CaCl_2$ 2%, PSB 1250 g, *Rhizobium* 1250 g, foliar spray of urea 2% and NAA 20 ppm at 35-40 DAS

Foliar nutrition

- Foliar spray of 0.5% boron in sunflower.
- Foliar spray of 0.5% KNO_3 in rabi sorghum
- Foliar spray of 0.5% 19:19:19 + $ZnSO_4$ and $FeSO_4$ in chickpea

Energy management

- Weed management through cycle drawn weeder in marginal farmers' field
- Mechanization of pigeonpea cultivation
- Mechanization of pigeonpea cultivation

Contingency crop planning

For *kharif* planning

a. Suggested contingency crops/ cropping systems and cultivars under delayed onset of monsoon

Delay by 2 weeks (4th week of June)

- Sunflower (KBSH-1, KBSH-53, DSFH3); pigeonpea (Maruti, TS-3-R); groundnut- spreading (GSP-39, S-230 and Mardur local); castor (NPH-1, RC-8, GCH-4, 48-1), sesame (E-8, DS-5), setaria (RS-118, HMT-1); green gram (Pusa baisaki, S-4).

Delay by 4 weeks (2nd week of July)

- Pigeonpea (TS-3 R); pearl millet (VPMH-7, VPMV-9, ICTP 8203 and ICMV 221); pearl millet + pigeonpea (2:1); groundnut (spreading) + pigeonpea (4:2); groundnut (spreading) + pearl millet (4:2); groundnut-spreading (GSP-39, S-230 and Mardur local); castor (NPH-1, RC-8,GCH-4), sesame (E-8, DS-1), setaria (RS-118, HMT-1); horse gram (GPM-6); moth bean (KBMB-1, BMB-40)

Delay by 6 weeks (4th week July)

- Pigeonpea (TS-3 R); pearl millet (VPMH-7, VPMV-9), horsegram (GPM-6), mothbean (KBMB-1, BMB-40).
- Fallow during kharif; follow in-situ moisture conservation practices like compartment bunding, ridges and furrows

Delay by 8 weeks (2nd week of August)

- Sunflower (KBSH-1, KBSH-41, KBSH-53, DSFH-3); horse gram (GPM 6); setaria (RS-118, HMT-1).

b. Crop, soil, water and nutrient management strategies during seasonal drought

Early season drought

- Thinning 30-35% of the population
- Weeding and repeated intercultivation
- Opening of conservation furrows at an interval of 15-20 m
- Opening up of ridges and furrows at 45 and 90 cm apart and across the slope 45 to 50 days prior
- Ratoon pearl millet, sorghum for rejuvenation after rains
- For crops like groundnut, take up urea spray (2% solution) immediately after rains for quick revival

Midseason drought

- Repeated intercultivation and removal of every third row
- Growing of short duration pulses

- Foliar spray of 0.5% KNO_3 or 0.5% 19:19:19 during dry spells
- Harvest sorghum for fodder purpose and allow for ratooning
- Spray antitranspirant i.e., 5% Kaolin
- Incorporate green gram in soil
- Mulching with available farm waste
- Give supplemental irrigation, if available

Terminal drought

- Harvest at physiological maturity stage and conserve the soil moisture for *rabi* crops
- Give supplemental irrigation, if available

For *rabi* planning

Suggested crops and varieties for delayed season

Chickpea (JG-11, JAKI-9218, GBM-2, BGD-111-1), safflower (A-1, A-2), sorghum + chickpea (2:4), safflower + chickpea (2:4), chickpea + linseed (4:2), wheat (DWR-137, DWR-2006)

Agro-hortisystems/Dryland horticulture technology

- **Tamarind based agri-horti system:** Tamarind seedlings can be planted at a spacing of 10 m x 3 m. Growing annual crops *viz.,* pearl millet/sunflower at 135 cm wider spacing between the tamarind tree rows. Tamarind trees start bearing from the 5th year onwards.
- **Tamarind based horti-pasture system in eroded soils:** Tamarind seedlings can be planted at a spacing of 10 m x 3 m or 10 m x 6 m. The pasture crops *viz.,* guinea and signal grass can be grown in between tamarind rows.
- **Simarouba based agri-horti system:** Simarouba can be planted at a spacing of 10 m x 10 m. In between the plants of simarouba within a row and in between rows of simarouba, guava can be planted. Grow annual crops *viz.,* chickpea, *rabi* sorghum etc., in between the rows of simarouba.
- **Sapota based agri-horti system:** Plant sapota grafts (variety Kalipatti) at 12 m x 12 m spacing in medium to deep black soils. In between sapota rows, the sowing of sunflower can be taken up during *kharif* followed by rabi sorghum + chickpea (2:1) or green gram during *kharif* followed by *rabi* sorghum + chickpea (2:1) or pearl millet (wider row) during *kharif* followed by sunflower (wider row). The annual crops can be sown till the canopy of sapota trees covers the entire land.

Technologies upscaled in convergence with various programmes

Many of the technologies developed at AICRPDA centre, Vijayapura were integrated and implemented through soil and water conservation and watershed programmes in the zone, Dryland Farming Mission of Karnataka, District Agriculture Contingency Plans, particularly Krishi Bhagya scheme of Govt. of Karnataka and also upscaled through KVKs, ATMA and other line departments.

Impact of dryland technologies developed at the Centre

- **Graded bunds with strip levelling:** The spread of the technology is to the tune of 50-60% of cultivable dry lands of Northern Karnataka. The increase in yield was 12-60% and the economic benefit ranged from Rs. 6000-8000 ha^{-1}.
- **Zingg conservation bench terraces:** The spread of the technology is to the tune of 20-30% of cultivable dry lands of Northern Karnataka. The increase in yield was 10.5-53% and the economic benefit was in the range of Rs. 12000-15000 ha^{-1}.
- **Vegetative live barriers and mechanical checks:** The technology is practiced in Bijapur, Raichur, H'matti watersheds, of course the total area coverage is not more than 2000 ha. The technology was evaluated for rabi sorghum, groundnut, and chilli. The increase in yield was 20-35% and the economic benefit was in the range of Rs 4000-5000 ha^{-1}.
- ***In-situ* moisture conservation measures:** Various in situ conservation measures viz., furrow and ridges, tied ridges, compartment bunding, set furrow cultivation and wide row spacing are being practiced all types of soil in the Northern Karnataka, these practices cover about 60-70% of the total dryland. The increase in yield was 10.5-25% and the economic benefit was in the range of Rs. 8000-10000 ha^{-1}.
- **Farm pond technology:** The farm ponds are being dug in all the districts of Northern Karnataka. Under the Krishibhagya scheme, almost 75000 farmponds was dug. This increased the cropping intensity and crop diversity in the farmpond commands.
- **Crop rotation of pigeonpea + greengram (2:4) rotated with onion during *kharif* sequenced with *rabi* sorghum/ chickpea during *rabi:*** The spread of the technology is to the tune of 8-10% of cultivable dry lands of Northern Karnataka. The increase in yield was 12-15 per cent and the additional economic benefit was in the range of Rs. 15000-20000 per ha.
- **Seed hardening of rabi sorghum and chickpea with 2% $CaCl_2$ and cow urine**: The technology is practiced in all districts of northern dry zone, spread of the technology is 20-25% of *rabi* sorghum and chickpea area. This practice increased grain yield by 23.7% over conventional practice and additional economic benefit was in the range of Rs. 3000-3500 ha^{-1}.
- **Intercropping of rabi sorghum + chickpea (2:4):** The technology is practiced in all districts of northern dry zone,

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spread of the technology is to the tune of 15-20% of rabi sorghum area. The additional economic benefit was in the range of Rs. 6000-7500 ha^{-1}.

- **Adoption of pigeonpea variety TS-3R:** The technology is practiced in all districts of northern dry zone and spread of the technology is to the tune of more than 80 % of pigeon pea area. The additional economic benefit was in the range of Rs.20000-25000 ha^{-1}.
- **Alternate land use systems:** Among various alternate land use systems, the Sapota based agri-horti system is more popular and practiced by farmers of Vijayapura, Bagalkote, Gadag and Belagavi districts of Karnataka. Around 2 to 5 percent of dryland farmers adopted this technology and additional economic benefit was in the range of Rs.15, 000 to 20,000 per ha.
- **Balanced nutrition in rabi sorghum:** This technology is practiced in about 55000 ha. The increase in yield was 10-15 per cent and the economic benefit was in the range of Rs. 6000-7000 ha^{-1}.

Way forward

- **Resource characterization:** The gram panchayat-wise the climate and soil resources information have to be converted into the form of atlases for better interpretation and utilization of the resources.
- **Comprehensive assessment of watershed management:** Identification of potential and future options for improving impact of watershed through more inclusive technological interventions, convergence, consortium, policy implications, institutional arrangements, funding mechanism and implementing guidelines.
- **Implementation of four waters concept: rainwater, surface water, soil water and ground water:** Spatial & temporal rainwater budgeting for seasonal crop planning in a participatory mode. Better water management in rainfed areas on a micro basin/ aquifer approach through different technological/ social options.
- **Evolving drought management strategies for major crops/cropping systems**: Cost effective technologies/ approaches for managing early and mid season droughts for stabilizing rainfed crop production.
- **Crop diversification to minimize risk and enhance income:** Combinations of cropping systems (including perennial components) and farming systems (involving animals) need to be tested for their risk minimizing ability and sustainability.
- **Developing farming system modules for different category of farmers and micro farming situations:** Farming systems approach for stabilizing the productivity and income are well known, but there are no clear modules of such farming systems suitable to different category of farmers or soil types/rainfall situations.
- **Protection and restoration of top soil and its productive constituents:** The efforts will be focused on conservation agriculture, residue application/recycling, ways and means of carbon sequestration in the soil, quality of residues and organic matter.
- **Precision sowing machinery for dryland crops:** Development of high precision sowing implements will help the farmers of dryland areas for completing their agronomic practices in time.

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