Overview of Dryland Agriculture Research and Achievements in Central, Eastern and Southern Dry Zone of Karnataka

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Brief history of the Centre

AICRPDA centre, Bengaluru was started in August, 1970-71. This centre is catering the research needs of dryland farmers of Central Dry Zone (Zone-IV), Eastern Dry Zone (Zone-V) and Southern Dry Zone (Zone VI) in the red loamy soils on finger millet based production system. The mandate of the project is (a) Optimizing the use of natural resources, *i.e.*, rainfall, land, water and to minimize soil and rainwater loss and environmental degradation, (b) To evolve simple technology for sustainability, increase crop productivity and economic viability, (c) To increase stability of crop production over years by way of improvements in natural resources and crop management systems and alternate crop production technologies matching the weather aberrations, (d) To develop alternate and sustainable land use systems and (e) To evaluate improved dryland technologies and transfer them to farmer's fields.

Agro-climatic zone characteristics

All India Co-ordinated Research Project for Dryland Agriculture, Bengaluru centre is located in Gandhi Krishi Vignana Kendra of UAS, Bengaluru on an area of 12 hectares. It is located in the Agro-climatic Zone (V): Eastern Dry Zone of Karnataka involving parts of Tumkur and entire Bengaluru (Rural), Bengaluru (Urban), Kolar, Chikballapur and Ramanagara districts having a total geographical area (TGA) of 17,96,838 ha with 8,48,120 ha area under cultivation. The climate in this zone is semi-arid. Out of the total annual average rainfall of 751.9 mm, the south-west monsoon contributes 54.70%, while 25.20% is from north-east monsoon and 18.5%. is received during summer. The onset (south-west) of monsoon is during first week of June.

Mean season-wise and annual rainfall and rainy days at AICRPDA centre, Bengaluru

Rainfall	Normal rainfall (mm)	Normal rainy days (No.)
South west monsoon (June-September)	508.9	33
North east Monsoon (October-December)	237.9	14
Winter (January-February)	10.90	00
Summer (March-May)	171.6	10
Annual	929.3	57

Major soil types

The zone has three major soil types and maximum area is covered by red loamy soil (48% of total geographical area), followed by red lateritic soil (33.49% of TGA) and red sandy loam (17.61% of TGA). The eastern taluks of the zone are largely composed of red sandy soils, while the western taluks have red loamy soils. The central part the zone has laterite soils and laterite gravelly soil (1.66% of to a limited extent).

Major rainfed crops

The major rainfed crops cultivated in the zone during *kharif* are finger millet, pigeonpea, maize, horsegram, groundnut, field bean and cowpea.

Dryland agriculture problems

The problems related to domain districts are as enlisted below:

Soil and land management

- Red soils have usually shallow depth and low moisture retention capacity. The water holding capacity of these soils varies between 10 and 15 cm per metre depth and this is not sufficient to carry the crops for more than a month after the cessation of rains. Therefore, only *kharif* crop is possible.
- Crusting on drying is a serious problem in seedling emergence and establishment of a good crop stand. Red soils are normally poor in NPK and very low in organic matter. At places, they are also deficient in Ca, S and B.
- The soils have low CEC (10-15 Cmol (p^+) kg^{-1} which results in low retention of exchangeable nutrients. These soils are highly erodible.

Crop production

- Due to delayed onset of monsoon, long dry spells during crop growth, early cessation of rains and lower water holding capacity of the soils, the crops suffer several cycles of drought.
- Heavy infestation of weeds.
- Lack of suitable implements for land development, sowing and inter-cultivation in various crops.
- Mono-cropping, lack of crop diversification and integrated farming system further reduces yield of crops.

Socio-economic

- The socio-economic survey conducted in several places highlighted the constraint of timely land preparation and sowing.

- The land holdings are very small and pose problems in implementing land development programmes.
- Due to poor economic status of the farmers, investment capacity and risk bearing status is less.
- Lack of support price for dryland crops and marketing problems and predominant role of middle man.
- Inadequate availability of agriculture inputs during the season and for contingent measures due to weather aberrations

Research initiatives since inception of the centre

AICRPDA centre, Bengaluru is catering the research needs of dryland farmers of Southern Karnataka comprising of Zone- IV, Zone-V and Zone-VI. The main focus is on location specific problems considering the agro-climatic zones, predominant rainfed production systems and socio-economic situation with major emphasis on rain water management, integrated nutrient management, energy management, crops and cropping systems, contingency planning, tillage and farm machinery, drought mitigation strategies and alternate land use system. Research findings of the centre are being evaluated on farmer's fields through Operational Research Project, National Initiative on Climate Resilient Agriculture and Rainfed integrated farming system.

The milestones in the research on dryland agriculture in Karnataka are:

1. Integrated Dryland Agriculture Development (IDLAD) project in collaboration with State Department of Agriculture and UAS, Bengaluru started from 1971-1981.
2. Action research-cum extension mode - Operational Research Project on Dryland Agriculture started during 1976.
3. Watershed development project during 1983-84 with two model watersheds, one at Mettemari in Kolar district and other at Bommenahalli in Mysore district started with the financial assistance from World Bank.
4. All India Co-ordinated Research Project on Agro-meteorology is in operation since from 1984.
5. Six ad hoc projects under soil and water conservation and fertilizer management themes were in operation from 1990's to mid of 2000.
6. The financial support by various organizations in India and abroad resulted in intensive work on dryland agriculture at Bengaluru centre. These were;
   a) Micro-nutrient management for enhancing the productivity of dryland crops (2001)
   b) Land use planning for management of agricultural resources (2001)
   c) Augmentation of green biomass for integrated nutrient management in dryland crop production (2003)
   d) Enabling rural poor for better livelihoods through improved natural resource management in semi-arid tropics of India (2003)
   e) The Rural-Urban Interface of Bengaluru: A Space of Transitions in Agriculture Economics and Society, Sub-Project on Effect of Agricultural Water & Nutrient Management on Farmers Livelihood (2016-2021)
   f) Standardization of conservation agriculture practices for Finger millet + Pigeonpea (8:2) intercropping system (2016 to till date)
   g) Comparative assessment of Aldor (30-00-05+7S) as an alternative to Urea on yield and nutrient use efficiency of rainfed maize in Karnataka (20121-2024)
   h) Studies on different granular fertilizers and bio stimulants on growth and yield of field crops (2022-23)
   i) Effect of foliar application of different nano fertilizers on nutrient use efficiency, productivity and economics of finger millet (2021-24)
7. The dryland agriculture technology park comprising various contingency crop planning measures consisting promising dryland technologies were demonstrated in a large scale at AICRPDA since from 2011 for the benefit of farmers and other dignitaries visiting and nearly 5-6 lakh farmers visit every year during krishi mela. Long term permanent manurial trial on finger millet mono cropping and finger millet-groundnut system is a heritage experiment in operation since from 1978 for convincing the stakeholders.
8. Custom hiring centre at NICRA village established during 2011 formed the basis for technical know-how for establishing Krishi Yantra Dhare programme by Government of Karnataka.

Significant achievements

Rainwater management

For effective conservation and management of rain water, graded bunds and levelling of graded border strips in deep red soils help to reduce the runoff losses and safe disposal of excess water, thereby increasing the crop yields. Apart from this, *Khus* and *Nase* grass as live bunds conserved soil and water by reducing the soil loss and runoff by 36% in slope up to 2.5 %. Vegetative barriers reduced runoff (11-12%) & soil loss (1.52-1.70 t/ha/year) as compared to control (soil loss: 2.5 t/ha/year) and helps in increasing the finger millet productivity. Also, *in-situ* soil moisture conservation through opening of conservation furrow improved productivity by 25-30 %. Mulching with crop residue in chilli resulted in enhanced moisture content in soil which helped in obtaining higher growth and green chilli yield (30-35%) than crop without mulching. Trench-cum-crescent bund helped in enhancing productivity and profitability by

impounding water resulting in conservation of higher moisture content of dryland orchards than that of no trenches. Lining of farm ponds (brick lining and brick compartment lining) with 400-500 microns gauged LDPE (Low Density Poly Ethylene) sheet with 8:1 ratio of soil-cement plastering to 5 cm thickness mortar in brick lining $1m^2$ rectangular brick compartments in brick compartment lining on all the four sides of the farm pond for higher stability helped in seepage control. The recommended size of farm pond is 250 m^3 per hectare catchment with 12 m × 12 m top length and width, 6 m × 6 m bottom length and width and 3 m depth with 1:1 slope. Subsoiling at 2 m interval + organic manure resulted in higher productivity and profitability breaking down the hard subsoil helping in high soil moisture conservation than the control.

Cropping systems

During early in the season growing of fodder pearl millet and cowpea followed by green chilli and transplanted finger millet, respectively was found to be promising double cropping systems with increased yield and B:C ratio (3.55 and 3.36 respectively) over sole finger millet. During delayed onset of monsoon, dry seeding of finger millet with higher seed rate (7.5 kg ha^{-1}) in anticipation of rain within 8-10 days was found to be successful. Practicing cereal based intercropping system (finger millet + pigeonpea (8:2)/ (10:2), maize + pigeonpea (1:1) and finger millet + castor (10:1)), pulse based (pigeonpea + field bean (1:1), pigeonpea + cowpea (1:1)) and oilseed based intercropping system (groundnut + pigeonpea (8:2), groundnut + castor (10:1)) and also bud nipping of castor were found to be promising by increasing the yield up to 25-30 % with conservation furrow in paired rows of pigeonpea than sole cropping. Also, alternate land use system involving finger millet and mango performed better over their respective sole crops in terms of growth and yield. Intercropping of amla with finger millet (1427 kg ha^{-1}) was found to be better intercrop among amla based agri-horti systems, resulting in higher net returns (₹. 29,446) than sole amla. Similarly, intercropping of custard apple with fodder maize (2346 kg ha^{-1}) was found to be better in custard apple based agri-horti systems, resulting in higher net returns (₹.1,19,672) and B:C ratio (6.67) than sole custard apple.

Integrated nutrient management

Integrated nutrient management *viz*., application of FYM @ 10 t/ha along with 100% NPK resulted in sustained finger millet productivity and soil health with a mean productivity of 1.8 t/ha. Similarly, *ex-situ* glyricidia green leaf manuring to supply 50% N +100% PK improved finger millet yield and also 50% N through green leaf manure and 50% NPK in finger millet - soybean-maize rotation system resulted in higher finger millet (3004 kg/ha), maize (2790 kg/ha) grain yield as compared to application of recommended NPK (2572 kg/ha, 1150 kg/ha, respectively). Among secondary nutrients, application of calcium through lime to 45% Ca saturation level (300-400 kg/ha of agricultural lime) + recommended NPK (25:50:25 kg/ha) to *Alfisols* improved the productivity of groundnut (1625 kg/ha) with a B: C ratio 2.5. Similarly application of sulphur @ 10 kg/ha in cowpea, blackgram, sunflower and groundnut increased seed yield (1350, 1160, 1230 and 2000 kg/ha, respectively) as compared to control. Application of higher dose of potassium (37.5 kg/ha instead of 25 kg/ha) increased the yield in finger millet (3.5-3.9 t/ha) and application of nitrogen @ 40 kg ha^{-1} and potassium @ 20 kg ha^{-1} resulted in higher grain and straw yield of little millet (730 & 1282 kg ha^{-1} respectively) and application of nitrogen @ 60 kg ha^{-1} and potassium @ 20 kg ha^{-1} resulted in higher grain and straw yield of foxtail millet (856 & 2063 kg ha^{-1}) than farmers practice (without potassium application). Also, application of zinc and boron along with NPK increased seed yield by 15-21% in finger millet, 8-31% in pulses and 15-37% in oilseeds over farmers practice. Crop rotation with legumes resulted in higher yield of finger millet. Mixing of finger millet seeds with complex fertilizers like DAP gave higher grain yield (2460 kg/ha) and B:C ratio (2.11) as compared to broadcasting method. Band placement of phosphatic fertilizer below the seed line resulted in higher grain yield of 5210 kg/ha compared to broadcasting (4690 kg/ha) in maize.

Crop improvement

Sowing suitable finger millet varieties (Long duration: MR-1, MR-6, Medium duration: GPU-28, KMR-301 and Short duration: GPU-28, KMR-316, ML-365) depending upon onset of monsoon is important contingent crop plan for aberrant weather and these promising varieties resulted in higher yield and also reduced the risk of crop failure. Among pulses, improved varieties in horse gram (PHG-9), pigeonpea (BRG- 1, BRG-2 and BRG-5), field bean (HA-3 and HA-4) and vegetable cowpea (IT-38956-1, PKB-4 and PKB-6) were promising varieties as compared to local cultivars. Similarly, among the different oilseed crops, improved high yielding varieties of groundnut (JL-24, Chintamani-2, ICGV-91114 and GKVK-5), sunflower, (KBSH-44 and KBSH-53), sesame (TMV-3), Niger (KBN-1 and KBN-2) and castor (DCS-9) were found to be promising under dryland condition. Further, Samrudhi a high yielding chilli variety was found to be promising for green chilli purpose and recorded 30% higher yield as compared to local varieties.

Energy management

Tractor drawn deep tillage equipment like disc plough, mould board plough and chisel plough conserves more moisture in the lower strata of soil and helped in better growth, yield of maize and pigeonpea and *in-situ* green manure incorporation through tractor drawn rotovator (covers one hectare in 90 minutes) resulted in higher yield (32.6%) with reduction in 50-60% energy costs. Further, tractor drawn post hole digger helped in reducing the cost of opening pits by 60-70% depending

upon size of pits. Modified bullock drawn seed drill for finger millet based intercropping system reduced sowing cost up to 30% (Operational cost is Rs. 400-500/- per hectare). Bullock drawn multi-furrow opener for groundnut sowing covered an area of 1.5-2.0 ha/day and cost of operation is Rs. 100-125/ha. Improved hand tools (improved sickles enhanced efficiency of operation by 25-30 %) and improved hand weeders require only 5 persons to cover one hectare in a day, whereas 25 persons are required for doing same work by traditional method. It reduced weeding cost up to 70% (Cost of operation is Rs. 500-600 per hectare). Adoption of post-harvest processing equipment like groundnut decorticator for efficient shelling (98%) reduces cost by 75% with operation cost of Rs. 250-300/quintal. Improved tractor drawn seed-cum-fertilizer drill helped in maintaining optimum plant population and reduced the seed rate up to 70% compared to farmer's practice (Broadcasting). This seed drill can also be used in different cropping system *viz*., intercropping, strip cropping *etc*.

Technologies developed

Rainwater management

- *Khus* and *Nase* grass as live bunds to conserve soil and water
- Deep trencher for soil moisture conservation in arable and non-arable lands
- Borewells recharge with filter bed using runoff water
- Farmpond for rainwater harvesting in red soils with lining for seepage control

Cropping systems

- Samrudhi: A high yielding chilli variety for rainfed situations
- Nipping in rainfed castor for higher productivity
- Groundnut based intercropping system
- Double cropping of cowpea-finger millet
- Dry seeding of finger millet under dryland condition

Inter cropping systems

- Finger millet + pigeonpea (8:2)
- Groundnut + pigeonpea (8:2)
- Pigeonpea + field bean (1:1)
- Pigeonpea + cowpea (1:1)
- Maize + pigeonpea (4:1)

Double / triple cropping systems

- Field bean-finger millet
- Cowpea-finger millet
- Sesame-finger millet
- Fodder pearl millet-cowpea
- Fodder pearl millet-chilli

Nutrient management

- Micronutrient application for higher yield of rainfed crops
- *In-situ* green manuring incorporation for higher finger millet productivity
- *Glyricidia* for green leaf manuring to improve soil health and crop productivity
- Potassium management in finger millet
- Potassium management in foxtail and little millet

Integrated nutrient management practices

Crop	INM practice
Finger millet	FYM / compost (7.5 t/ha) eupatorium green manure (9-9.5 t/ha) / horsegram *in-situ* incorporation+ recommended NPK + bio fertilizers (seed treatment with *Azospirillum* @ 200 g/ha) + 50:40:37.5 kg NPK/ha and Zn 5 kg/ha and Borax 4 kg/ha
Sorghum	FYM/ compost (5 t/ha) + recommended NPK + seed treatment with *Azospirillum* @ 500 g/ha and PSB @ 500 g/ha
Maize	FYM / compost (7.5 t/ha) + 100:50:25 kg NPK/ha
Horsegram	25:38:25 kg NPK/ha + seed treatment with *Rhizobium* @ 500 g/ha + PSB @ 500 g/ha
Pigeonpea, cowpea and field bean	FYM / compost (7.5 t/ha) + 25:50:25 kg NPK/ha +seed treatment with *Rhizobium* @ 500 g/ha + PSB @ 500 g/ha
Groundnut	Glyricidia @ 2.5-3.0 t/ha + FYM / compost (7.5 t/ha) + 25:50:25 kg NPK/ha + seed treatment with *Rhizobium* @ 400 g/ha and PSB @ 1 kg/ha + recommended gypsum + zinc @ 10 kg/ha and boron @ 10 kg /ha
Sunflower	FYM/compost (5 t/ha) + 13:25:25 kg NPK/ha
Castor	FYM/compost (5 t/ha) + 38:50:38 kg NPK/ha
Niger	FYM/compost (5 t/ha) + 20:40:20 kg NPK/ha
Minor millets	FYM/compost (5 t/ha) + 20:20:20 kg NPK/ha

Foliar nutrition/spray

Crop	Foliar nutrition
Finger millet	• Foliar spray of 2% KNO_3 • Foliar spray of Thiourea (250 g ha^{-1}) • Foliar spray of 1% KCl

Energy management

- Modified bullock drawn seed drill for finger millet
- Improved hand tools and equipments in dry farming
- Tractor drawn rotovator for *in-situ* green manure incorporation in *Alfisols*
- Mixing of finger millet seeds with DAP fertilizer for sowing by seed drill

- Management of soil surface crust in *Alfisols*
- Tractor drawn deep tillage equipment for *Alfisols*
- Groundnut decorticator for groundnut shelling
- Bullock drawn automatic seed drill for finger millet + pigeonpea intercropping system

Alternate land use

- Mango/sapota/tamarind + finger millet agri-horti system for sustainable income in drylands
- Amla based agri-horti system involving cereals and pulses in drylands
- Custard apple based agri-horti system for sustainability

Integrated farming systems

- Integrated farming system for land use planning and sustainable management of natural resources in drylands

Contingency crop planning

For *kharif* planning

a. Crop/cropping system for normal onset of monsoon: June 1st week

- Finger millet - MR-1, MR-6, L-5, KMR-301, HR-911
- Maize - MAH 14-5, Hema, Nithya Shree
- Greengram –PS-16, KKM-3, PDM 84-178
- Black gram – T-9, Rashmi, LBG 791
- Pigeonpea - BRG-2, TTB-7
- Sesame- JT-1, TMV-3
- Cowpea - TVX-944-2E, IT-38956-1, KBC-1, KBC-2
- Groundnut - JL-24, K-134, GPBD-4
- Intercropping systems: Finger millet + pigeonpea (8:2); finger millet + field bean (4:1); finger millet + niger (4:1); maize + pigeonpea (4:1); maize + french bean (3:1)

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

Delay by 2 weeks (3rd week of June)

- Intercropping systems: Finger millet + pigeonpea (8:2); finger millet + field bean (4:1) finger millet + niger (4:1); finger millet (MR-1, MR-6 L-5); maize + pigeonpea (3:1); maize + french bean (3:1); pigeonpea (BRG-2, TTB-7)
- Cowpea (TVX-944-2E, IT-38956-1); pigeonpea (BRG-2)

Delay by 4 weeks (1st week of July)

- Intercropping systems: Finger millet + pigeonpea (8:2); finger millet + field bean(4:1); Finger millet + niger
- Finger millet - MR-1, MR-6, L-5, HR-911
- Groundnut - JL-24, TMV-2, GPBD-4, K-134, VRI-2
- Pigeonpea - BRG-2, TTB-7
- Cowpea - TVX-944-2E, IT-38956-1
- Maize + pigeonpea (3:1)
- Pigeonpea BRG-2 as intercrop

Delay by 6 weeks (3rd week of July)

- Finger millet - GPU-28
- Little millet - CO-2, PRC-3
- Foxtail millet - RS-118,K-221-1
- Inter-cropping of maize with cowpea, blackgram, greengram and field bean

Delay by 8 weeks (1st week of August)

- Finger millet – GPU-28, GPU-66, ML-365, GPU-48, GPU-26, KMR-204
- Little millet - CO-2 and PRC-3
- Foxtail millet - RS-118 and K-221-1
- Cowpea- KBC-1, KBC-2, IT 38956-1, KN-5, KBC 9
- Soybean- MAUS-2 KBS-23
- Sunflower- KBSH-44, KBSH-53, KBSH-78
- Field bean - HA-3, HA-4 and HA-5
- Cowpea - IT-38956-1

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

Early season drought

- Re-sowing with short duration varieties, if germination is failed
- Staggered nursery raising of finger millet and transplanting
- Thinning and gap filling to maintain optimum plant population
- Contingency crop: Medium duration variety *viz*., GPU-28, and short duration variety *viz*., GPU-48 for early, delayed and very late monsoon. For late *kharif*, cowpea (IT 38956-1), horsegram (PHG-9), sunflower and minor millets viz., same, navane, haraka and oodalu can be sown.

Mid-season drought

- Repeated inter-cultivation coupled with weeding and weed mulching
- Foliar spray of 1% KNO_3
- In finger millet-thinning, pruning leaf tips, postponement of top dressing (till optimum moisture is available) thinning plant population and mulching
- Soil mulching
- Protective irrigation at critical stages using harvested farm pond water
- Opening of conservation furrows at an interval of 10-15 m
- In groundnut, earthing up, apply gypsum after receipt of rains

- Controlled grazing by animals to reduce excess vegetative growth and to minimize transpiration in finger millet and horsegram

Terminal drought

- Removal of cob less plants and use as green fodder
- Harvest at physiological maturity stage (pigeonpea and field bean)
  irrigation if available
- In case of severe drought, maize crop to be harvested for table purpose, field bean and pigeonpea to be harvested as green pods ,topping of maize if grain filling stage is completed
- Harvest whatever crop is available and immediately conserve the soil moisture for *rabi*
- Irrigate crops through harvested rain water as life-saving

RTCPs info for delayed onset of monsoon and early/midseason/terminal drought in various crops

Condition		Suggested contingency measures		
Early season drought (delayed onset)		**Crop/ cropping system**	**Change in crop/ cropping system**	**Agronomic measures**
Delay by 2 weeks June 3rd week		Finger millet Maize Groundnut Pigeonpea Cowpea and castor	a. Finger millet + pigeonpea (8:2) b. Finger millet + Field bean (4:1) c. Finger millet: MR-1, MR-6, L-5	Conservation furrow
		Maize Maize + pigeonpea (1:1)		• Use of downey mildew and leaf sheath blight resistant maize hybrids (NAH 2049, NAH 1137). Seed treatment with metalaxyl @ 4 g/kg
		a. Groundnut + pigeonpea (8:2) b. Groundnut + Castor (8:1)		• Seed treatment with *Rhizobium* • Soil application of gypsum @ 500 kg/ha, earthingup. $ZnSO_4$ application @ 10 kg/ha
		Pigeonpea: BRG-1, BRG-2, BRG-5		Thinning, ridges and furrow
		No change	-	
Delay by 4 weeks July 1st week Pigeonpea Field bean Groundnut + Pigeonpea Nipped castor		a. Finger millet + pigeonpea (8:2) b. Finger millet + Field bean (4:1)	• Continued up to July end for finger millet based system • Finger millet: MR-1, MR-2, MR-6, L-5 • Maize + pigeonpea (1:1)	• In finger millet: Dry sowing 8-10 days before rains with 15-20 % higher seed rate • Nursery – transplanting (Long duration varieties of finger millet) • Seed hardening (18 hours soaking in water followed by 24 hours shade drying) • Thinning to retain one seedling at 30 cm in pigeonpea • Inter cultivation • Conservation furrow • In groundnut: Seed treatment with Rhizobium and soil application of gypsum @ 500 kg/ha, earthing up. ZnSO4 application @ 10 kg/ha. Use pigeonpea (BRG-2) for intercropping with finger millet
		Pigeonpea: BRG-1, BRG-2		
		No change		
		Continued up to 15th July Groundnut: GKVK-5, KCG-6, ICGV-91114		
		No change		
Delay by 6 weeks July 3rd week	Shallow red soils	Finger millet	No change: Finger millet MR-1, MR-2, MR-6, L-5 a. Finger millet + pigeonpea (8: 2) b. Finger millet + field bean (8:1)	• In finger millet: Dry sowing 8-10 days before rains with 15-20 % higher seed rate • Nursery–transplanting (Long duration verities of finger millet) Seed hardening (18 hours soaking in water followed by 24 hours shade drying)
		Pigeonpea	No change	Thinning to retain one seedling at 30 cm
		Groundnut	No change	In groundnut: Seed treatment with *Rhizobium*, soil application of gypsum @ 500 kg/ha, earthing up. $ZnSO_4$ application @ 10 kg/ha

Condition	Crop/ cropping system	Suggested contingency measures	
		Change in crop/ cropping system	Agronomic measures
Delay by 8 weeks August 1st week	Finger millet	GPU-28, GPU-66, ML 365, HR 911	• In finger millet: Dry sowing 8-10 days before rains with 15-20% higher seed rate • Nursery raising of seedlings of medium duration varieties and transplanting • Seed hardening – 18 hrs. soaking in water followed by 24 hrs shade drying Inter cultivation and opening of conservation furrow
	Field bean	HA-3 and HA-4	
	Cowpea	TVX-944, IT-38956-1	
Delay by 10 weeks August 3rd week	Finger millet	Short duration variety: GPU-48, GPU-84	• Finger millet-Dry sowing 8-10 days before rains with 15-20% higher seed rate • Nursery raising and transplanting • Seed hardening • Intercultivation and conservation furrow Thinning in deficit rainfall situation
	Field bean	HA-4	
	Foxtail millet	CO-2, PRC-3	
	Little millet	RS 118	
	Niger	No-71, KBN-1	
	Horse gram	PHG-9	
	Cowpea	IT-38956-1	
	Fodder crops	Fodder bajra, fodder maize and fodder sorghum	
Delay by 12 weeks September 1st week	Field bean	HA-4	• Finger millet- Dry sowing 8-10 days before rains with 15-20% higher seed rate • Nursery raising and transplanting • Seed hardening • Intercultivation and conservation furrow • Thinning in deficit rainfall situation
	Little millet	RS 118	
	Foxtail millet	CO-2, PRC-3	
	Niger	No-71, KBN-1	
	Horse gram	PHG-9	
	Cowpea	IT-38956-1	
	Fodder crops	Fodder bajra, fodder maize and fodder sorghum	

Condition	Normal Crop/ cropping system	Suggested contingency measures	
		Crop management	Soil management
Early season drought (Normal onset, followed by 15-20 days dry spell after sowing leading to poor germination/ crop stand, etc.)	Finger millet Finger millet + Pigeonpea (8:2) Maize Maize + PP(1:1) Maize + FB (3:1) Maize + Cowpea (3:1) Pigeonpea Field bean GN GN + PP (8:2) Cowpea	• Thinning and gap filling • Resowing if poor establishment • Contingent crops and varieties	• Inter-cultivation to create dust mulch • Weeding and mulching • Protective irrigation at places where there are facilities • Opening conservation furrow

Condition	Normal Crop/ cropping system	Suggested contingency measures	
		Crop management	**Soil management**
Mid season drought (long dry spell) At vegetative stage	Finger millet Finger millet + Pigeonpea (8:2)	• Finger millet –Thinning, postponement of top dressing (till optimum moisture is available)	• Intercultivation to create dust mulch • Opening conservation furrow between paired rows of pigeonpea • Grazing flag leaf in finger millet • 1% potassium spray
	Maize + Pigeonpea (1:1)		
	Pigeonpea		
	Field bean		
	Groundnut		
	Cowpea		
	Groundnut + Pigeonpea	• Earthing up, apply gypsum @ 500 kg/ha after receipt of rains. Life saving irrigation	
	Horse gram	• Thinning	• Intercultivation to create dust mulch

Condition	Normal Crop/ cropping system	Suggested contingency measures	
		Crop management	***Rabi* crop planning**
Terminal drought	Finger millet: MR-1, MR-2, MR-6, L-5, HR-911 FM + PP (8:2) FM + FB (4:1)	• Life saving irrigation • Harvest pulses (pigeonpea and field bean) at physiological maturity for vegetable purpose	Cowpea, field bean, horse gram, chickpea, fodder crops like fodder bajra and fodder maize
	Maize Maize + Pigeonpea (1:1)	• Protective irrigation • Topping of maize if grain filling stage is completed • Harvest pigeonpea at physiological maturity for vegetable purpose	
	Pigeonpea	• Harvest for vegetable purpose	
	Field bean	• Field bean to be harvested as green pods	
	GN + PP	• Pigeonpea to be harvested as green pods	
	Cowpea	• Harvest for vegetable purpose	

Unusual rains (Untimely, unseasonal etc.)

Condition	Suggested contingency measures			
Continuous high rainfall in a short span leading to water logging	**Vegetative stage**	**Flowering stage**	**Maturity stage**	**Post-harvest**
Finger millet	• Draining excess water • Weeding and top dressing with urea	• Draining excess water	• Draining excess water • Tying up of lodged plant • Harvesting at physiological maturity	• Proper drying and storage of grains
Groundnut	• Safe disposal of excess of water	• Safe disposal of excess of water	• Safe disposal of excess of water	• Dry in shade and turn heap frequently
Pigeonpea	• Safe disposal of excess of water	• Safe disposal of excess of water	• Safe disposal of excess of water • Harvesting and drying of plants • Plant protection measures for control of pod borers and other pests	• Proper drying and storage with pest management practices

For *rabi* planning

Crops and varieties for normal season

Chickpea - JJ 11, Annigere-1

Fodder maize - SA tall

Fodder bajra - Giant bajra

Agroforestry systems

Mango/sapota/amla/ custard apple based agri-horti systems with finger millet/fodder maize as intercrops

Crop	Inter row spacing
Mango	5 m ×5 m, 8 m × 8 m
Sapota	10 m × 10 m, 12 m × 12 m
Amla	6 m × 6 m, 10 m × 10 m
Custard apple	5 m ×5 m

Agroforestry

Trees for fodder

Crop	Recommended spacing		Management Practice	Recommended Inter crops
	Boundary planting	Orchards		
Melia dubia	3 × 3 m	5 × 5 m	• Regular pruning • Removing of termites • Weeding should be done twice per month upto the age of three year plantation	Finger millet, soya bean, field bean, pigeonpea
Subabool	3 × 3 m	5 × 5 m		
Sesbania grandiflora	3 × 3 m	5 × 5 m		Finger millet, soya bean, field bean, pigeonpea and vegetable crops
Casuarina, Silver oak	-	2 × 2 m	• Pruning, weeding and thinnin	-

Agri-Pastures

Silver oak + CO-3 multi-cut fodder

Technologies upscaled in convergence with various programmes

Nine technologies under rain water management, 17 technologies under cropping systems, 12 technologies under integrated nutrient management, 9 technologies under participatory varietal selection/ crop improvement, 12 technologies under energy management theme were published in package of practice of UAS-Bengaluru and the same technologies were implemented and upscaled in farmer's field in collaboration with KVK, department of agriculture and department of watershed, Government of Karnataka.

District wise contingency plan and various drought proofing action plans in the domain agro-climatic zones of the centre were upscaled with the help of KSDA. The centre, in collaboration with other AICRP schemes such as AICRP on small millet, sunflower, pigeonpea and arid legumes developed various improved varieties of crops *viz.*, Samrudhi chilli, IT-38956-1 cowpea, PHG-9 horsegram, BRG-5 pigeonpea which helped to increase the productivity of these dryland crops. All these varieties were evaluated and upscaled through front line demonstrations in farmers field, organising field day, etc., in the domain area through KVK's of SAU's, ATMA and other line departments operating in the zone. Alternate land use management practices, viz, intercropping in custard apple, amla, mango and sapota and seed production of new varieties of seeds was up scaled through department of horticulture under NHM scheme.

The soil fertility management was upscaled through Bhoo Chethana program of KSDA & ICRISAT. The SHG's and FPO's are operating at village level helped in upscaling of dryland technologies. The agromet advisory regarding climate change and a suitable measure that has to be followed was implemented with the help of AICRP on Agrometerology. The farm pond technology through Krishi Bhagya scheme, soil and water conservation measures such as deep ploughing, bunding and deep trenches in orchards through watershed program helped in upscaling the dryland technologies.

Impact of technologies

Crop management practices like crop cultivation across the slope with *khus* and *nase* as live barrier at 15 m interval for land slope of 1-3% reduced and runoff by 36% and soil loss from 1.52 - 1.70 t/ha/year. Similarly opening of trenches up to 30-60 cm depth and width 50-60 cm using tractor was found to be suitable for conserving runoff water and this was more suitable for fruit orchards which helped in getting higher yield. Modified seed drill helps in maintaining recommended row to row spacing of 30 cm with reduced implement weight by reducing one bowl, as compared to local implement. It reduces sowing operation cost up to 30%. The cost of the modified seed drill is Rs.3000/-. This seed drill has been used by many farmers in few villages of Kanakapura through Operational Research Project and also in Nelamangala through National Initiative on Climate Resilient Agriculture project. Farmers realized that newly modified seed drill is good and convenient to control weed growth.

By recharging bore well the discharge of bore well was improved which led to effective utilization of runoff water in dryland and enhanced the ground water level and yield of defunct bore wells. The farm ponds lined with 400-500 micron gauge LDPE helped in minimizing seepage losses and stored water could be used for two protective irrigations during 20-25 days long dry spell

for horticulture crops around the farm pond. This technology was taken up as one of the flagship programmes under "Krishi Bhagya" scheme of KSDA which led to popularization of farm ponds. The farm pond technology (12 m × 12 m top width and length, 6 m × 6 m bottom width and length, depth of 3 m with 1:1 side slope for one hectare catchment area) is developed by AICRPDA centre, Bengaluru. This technology is integrated into Krishi Bhagya scheme of Karnataka and upscaled in Bengaluru Rural District. About 4 farm ponds are dug out in 4 farmer's fields at Bengaluru Rural District. The stored rainwater in farm pond is being used for supplemental irrigation in rainfed crops resulting 20-25% in yield advantage/ha and 15-20% income benefit/ha to the farmers. Similarly, at Kolar 14,424 numbers of farm ponds are dug in farmer's field during 2015-2020 by the KSDA with the technical support of AICRPDA Bengaluru centre. The stored rainwater in farm pond is being used for supplemental irrigation in rainfed crops.

Finger millet is grown in an area of 10.2 lakh ha in domain with mean productivity of 1800 kg/ha during normal rain fall. By sowing suitable variety depending upon onset of monsoon, productivity level can be maintained on average of 2100-2200 kg/ha under rainfed condition. Sowing suitable finger millet varieties depending upon onset of monsoon will increase the yield and also reduce risk of crop failure. Farmers have the option of choosing a right variety for right time of sowing.

Improved high yielding varieties of pigeonpea (BRG-1 and BRG-2), field bean (HA-3 and HA-4) and vegetable cowpea (PKB-4 and PKB-6) are recommended for rainfed situation based on their long- term performance. Horse gram is grown in an area of 0.69 lakh ha in the domain with a mean productivity of 700-725 kg/ha. Horse gram variety PHG-9 is high yielding, fairly tolerant to powdery mildew and has bold grain with yield of 850-950 kg /ha. New variety of cowpea IT38956-1 tolerant to leaf spot and rust disease suits well for both early and late *kharif*, also well suited for double and intercropping system in rainfed agriculture. Among the different oilseed crops improved high yielding varieties of groundnut - JL-24, Chintamani-2, ICGV 91114, GKVK-5, sunflower - KBSH-44 and KBSH-53 are suitable for delayed onset of monsoon as contingent crop, sesame - TMV-3 (suitable for double cropping), Niger - KBN-1 and castor - DCS-9 suitable for intercropping in groundnut) helped in increasing productivity in dryland agriculture. Samrudhi, a high yielding open pollinated variety of chilli performed well in dryland situation. Adoption of this variety in 30% of total chilli area could sustain, green chilli yield.

Growing of finger millet and pigeonpea 10:2 or 8:2 row ratios using seed drill and maintaining 60 cm spacing between paired row of pigeonpea helps in conserving water in the furrow and also the productivity of finger millet can be improved to 2.2-2.5 t/ha during normal rainfall and risk can be reduced during unfavourable rainfall. This technology is integrated into KSDA plans/programme in Bengaluru Rural District, Karnataka. This technology is being adopted on 500 farmer's field in the district resulting in 10-15% yield advantage and 15-20% income benefit to the farmers. Adoption of pulse based intercropping system involving pigeonpea + field bean (1:1), pigeonpea + cowpea (1:1), pigeonpea + groundnut (2:4) helped in obtaining 30-40% higher income than sole crops and also the incorporation of crop residue enhanced the soil fertility. Intercropping groundnut + pigeonpea (8:2), groundnut + castor (8:1) is popular. By adopting this intercropping system, there is good scope for improving the productivity from 1.4 to 1.6 t/ha during normal rainfall and risk can be reduced during unfavourable rainfall years. Similarly, bud nipping in rainfed castor helps in getting higher yield up to 40%. Intercropping nipped castor with finger millet recorded higher castor equivalent yield compared to sole castor. If the improved cropping system is adopted, there is good scope for improving the productivity to 1.7 t/ha during normal rainfall years and risk can be reduced during unfavourable rainfall years.

Bimodal distribution of rainfall is favourable for double cropping thus double cropping of cowpea followed by finger millet in assured rainfall area helped in sustaining yield and getting additional income. By following dry sowing of finger millet, the productivity can be enhanced from 3.74 to 4.03 t/ha and large area can be sown prior to rain. If this double cropping of cowpea followed by finger millet in assured rainfall areas of the state (at least 50 per cent of finger millet area), certainly it is possible to realize an additional cowpea yield of 2,65,200 tons or a monetary benefit of Rs. 1.01 crore apart from succeeding finger millet with improved soil health.

In-situ incorporation of horse gram biomass (18-20 t/ha) helped in enhancing grain yield upto 2.5 t/ha and saving 50% recommended nitrogen to finger millet. Similarly, *ex-situ* glyricidia green leaf manuring to supply 50% N +100 % PK improved finger millet yield and the productivity can be increased with saving of 50% NPK besides maintaining good soil health. Applying higher dose of potassium (37.5 kg/ha instead of 25 kg/ha) increased the yield, thus by upscaling of this improved nutrient management practice, the productivity can be further improved to 3.5-3.9 t/ha. Application of NPK + lime to 45% Ca saturation (300-400 kg/ha of agricultural lime) to *Alfisols* improved the productivity of groundnut. Application of sulphur @ 10 kg/ha to cowpea, blackgram, sunflower and groundnut recorded 25% higher yield. Application of zinc and boron with NPK increased seed yield of finger millet, pulses and oilseeds.

Integrated nutrient management, *viz.,* application of FYM @ 10 t/ha with 100% NPK resulted in sustained finger millet

productivity and soil health with a mean productivity of 1.8 t/ha. Mixing of finger millet seeds with complex fertilizers like DAP gives higher grain yield as compared to broadcasting method of fertilizer application. Application of farm yard manure (FYM) @ 10 t/ha or maize residue @ 5 t/ha or 2 t/ha of gypsum depending upon soil pH to finger millet helps in reducing soil crusting with increased seedling emergence, reduced yield loss to the extent of 30-40% besides maintaining good soil productivity. Rotation of finger millet with groundnut integrated with organic manure resulted in sustained finger millet productivity and soil health as compared to monocropping of finger millet. Rotation of finger millet with groundnut resulted in 19-20% increased yield and soil fertility.

Using deep tillage equipments like disc plough, MB plough and chisel plough ensures higher yield due to in-situ conservation of moisture. Sowing finger millet using modified seed drill ensures recommended row spacing with reduced drudgery of operation. Improved hand weeder reduce weeding cost up to 70%, and increase the efficiency by reducing the energy required to operate. Likewise, improved sickles reduce drudgery to the extent of 25-30% compared to locally available sickles.

Custom Hiring Centre (CHC) for farm implements/machinery in Chikkaputtyanaplaya village, Bengaluru Rural District, Karnataka State is established in the year 2011 by AICRPDA Centre, Bengaluru under All India Coordinated Research Project for Dryland Agriculture (AICRPDA) - National Innovations in Climate Resilient Agriculture (NICRA). This CHC is enabling the farmers to hire farm implements/machinery at an affordable cost for various agricultural operations in various crops with high energy use efficiency. This has enabled timely operations and promoted small farm mechanization.

Way forward

The Karnataka state has 7.0 m ha of net rainfed area out of 10.3 m ha of net sown area accounting for nearly 70 per cent of the total cultivated area. About 67 per cent of the total cultivated area receives an average rainfall of less than 750 mm with intermittent dry spells. The rainfed areas suffer from constraints with respect to soil and crop management and socio-economic issues. Reduction in human resource due to exodus of rural youth to nearby towns has added another dimension to dryland problems.

The All India Coordinated Research Project for Dryland Agriculture (AICRPDA) has carried out location specific adaptive research in a network mode which resulted in development of improved dryland technologies in the areas of rainfed cropping systems, drought management, soil and water conservation, nutrient management and farm mechanization. Some of these technologies have already formed part of package of practices for crops in different states. However, in view of the increasing importance of rainfed agriculture and the need for boosting productivity, emphasis is required on climate smart natural resource management such as development of best management practices (BMP), water conservation and soil aquifer treatment (SAT) for sustainable agriculture, application of communication & information technology and developing and implementing IT solutions in rain water management, nano-technology for soil and water conservation, evaluation of soil moisture retainers bio-irrigation technique as a drought proofing strategy, expansion of alternate land use practices as a long term strategy, promoting commercial dryland agriculture with protective cultivation under harvested rain water, harnessing solar energy in non-crop space including harvested water bodies to fulfil the farm energy demand, *e*-dryland portal with emphasis on large scale dissemination of weather forecast, agro-advisory and interactive modules. Technologies for sustainable soil health management includes enhancing moisture holding capacity through use of alternate sources of organic manures, sub soil manuring to improve nutrient availability from deeper layers, studies on carbon emission and carbon sequestration under different land use systems, conservation agriculture, and geospatial technologies for soil resource management. In crop improvement, screening of genotypes for multiple resistances in different dryland crops with major emphasis on drought tolerance, short duration for climate extremities is essential. Mechanization and secondary agriculture plays important role which includes nano coated machinery for energy efficient small scale operation, crop centric seed to seed mechanization facilities for small holder farm, and secondary agriculture including post-harvest management. The above listed are some of the issues to cater to the need of the hour to increase the productivity.