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Overview of Dryland Agriculture Research and Achievements in Scarcity Zone of Maharashtra

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Brief history of the Centre

On recommendation of the Royal Commission on Agriculture in India, the first systematic and scientific approach to solve the problems of dry farming was made in the year 1923 and systematic research on dry farming in the Scarcity tracts of Bombay-Deccan was first initiated at Manjari, Pune. The work in the early years was directed towards soil moisture conservations. After working for few years, it was realized that the problem was vast and complex and required simultaneous research on different aspects such as disposal of rainwater, soil characters, water requirement of plants etc. The results of these preliminary investigations formed a basis for an elaborate and comprehensive programme of research undertaken in the years that followed. The comprehensive research on rainfall and other climatic factors, disposal of rain water and soil erosion, physico-chemical characteristics of soil, physiological studies of important millets grown in dry tracts, agronomy or soil management was initiated at Solapur under the guidance of Chief Investigator from 1933. The dry land agriculture research station was established in 1933 to undertake dry farming research with assistance from the Imperial Council of Agricultural Research, Delhi. It was then made permanent feature of the State Department of Agriculture after 1944. A technique known as Bombay Dry Farming Method laid stress on better utilization of moisture by reducing plant densities and better inter cultivation. Fertilizer use was not envisaged at that time, crop and varietal diversity was also not adequate which resulted in emphasizing the growing of few crops only. Further, weather observations were not considered to plan different strategies of crop production. The All India Co-ordinated Research Project for Dryland Agriculture centre was started in 1970-71 at Solapur.

Agro-climatic zone characteristics

This zone covers geographical area of 73.23 lakh ha with gross and net cultivated area of 58.42 and 53.0 lakh ha. It suffers from very low rainfall with uncertainty and ill distribution. The occurrence of drought is noted once in three years and the duration of dry spell varies from 2-10 weeks. The climate of the zone is semi-arid. Out of the total annual average rainfall of 721.4 mm with 41 rainy days, the south-west monsoon contributes 74 % and north-east monsoon 17%. The normal onset of monsoon is during first fortnight of June and normal withdrawal is during first fortnight of October. The mean maximum temperature and mean minimum temperature in the zone are 33.6°C and 19.9°C, respectively.

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

Rainfall	Normal rainfall (mm)	Normal rainy days (No.)
South west monsoon (June-September)	535.2	24
Post-monsoon (October-December)	125.5	13
Winter (January - February)	8.1	2
Summer (March-May)	52.6	2
Annual	721.4	41

Major soil types

The major soil types in the zone are shallow black soils (67.8%), medium black soils (13.9%) and deep black soils (18.2%)

Major rainfed crops

The major rainfed crops cultivated in the zone during *kharif* are pigeonpea, sunflower, pearlmillet, blackgram, cowpea, greengram and during *rabi* are sorghum, chickpea and safflower

Dryland agriculture problems

Climate/rainfall related

- Variable rainfall, intensity and distribution of rainfall, late onset of monsoon, early withdrawal of monsoon, prolonged dry spells, high temperature, low relative humidity, hot dry winds

Soil related

- Inadequate soil moisture, poor organic matter content, poor soil fertility, soil erosion, presence of hard pans

Crop related

- Low inputs
- Low adoption of improved dryland practices
- Low crop diversification
- Poor farm mechanization

Socio economic issues

- Lack of capital, labour problem, fragmented land holding, exodus of rural labourer to urban areas, decreasing availability of animal draft power

Significant achievements/findings

Rainwater management

- Furrow irrigation method using 6 cm water per irrigation increased grain and stover yield of sorghum.
- Due to soil conservation works (Nala checks) it was observed that there is an increase in groundwater table of the wells situated on the downstream sides of the nala and also there is an increase in area under irrigation.
- Vegetative barrier of *Leucaena leucocephala* is recommended for soil and water conservation
- Harvesting of the runoff water in farm pond during rainy season and utilization of harvested water as protective irrigation during 35 to 41 MW (27th August to 14th October) for *kharif* crop during the dry spells at flowering stage and or for *rabi* crops during the dry spells at initial development stage.

Nutrient management

- A fertilizer dose of 50 kg N and 25 kg P_2O_5 is recommended for hybrid pearl millet in dry farming area. Looking to the profitability of nitrogen application and the response per unit and to cover larger area for higher production a dose of 50 kg N ha $^{-1}$ is recommended to the safflower crop under dryland conditions.
- For improvement of *rabi* sorghum production as well as for improvement of soil fertility addition of 25 kg N ha^{-1} through crop residue (sorghum stubble) + 25 kg N ha^{-1} through urea, 2-3 months before sowing is recommended. Addition of FYM 7.5 t ha^{-1} + Murrum 15 t ha^{-1} in every summer season in the surface soil layer of problematic (sodic) soils for improvement of productivity of dryland is recommended.
- For improvement of soil fertility and higher yield of pearl millet, two harrowing before sowing and one weeding at 15-20 days and one hoeing at 30-35 DAS is recommended along with application of 25 kg N through organics (FYM 5 t + *Leucaena* loppings 1.75 t) and 25 kg N + 25 kg P_2O_5 ha^{-1} through fertilizers is recommended.
- In Scarcity zone of Maharashtra on medium deep soils, during the *kharif* season cowpea grown as a green manuring crop and incorporated at flowering *in-situ* either green lopping or green manuring followed by *rabi* sorghum with recommended dose of fertilizer (50:25 kg N: P_2O_5 ha^{-1}) is recommended for higher grain and fodder yield and for improving soil fertility.
- Spraying of 1% Potassium Nitrate (KNO_3) at 35 and 55 days after sowing along with recommended dose of fertilizer (50:25:25 N: P_2O_5: K_2O kg ha^{-1}) is recommended for higher yield of *rabi* sorghum and mitigation of drought in medium deep black soils of scarcity zone of Maharashtra.

Energy management

- Multipurpose farming machine is good and is developed for primary tillage, secondary tillage and sowing.
- Application of P either at sowing or 3 weeks prior to sowing of *rabi* sorghum is recommended.
- Considering the draft, field capacity and cost of operation, the Jyoti and Shivaji multipurpose seed drill ranked first amongst the seven different ferti seed drills.
- The multipurpose "*Phule Sheti Yantra"* developed by Mahatma Phule Krishi Vidyapeeth is recommended for harrowing, cultivating and sowing of different crops.
- One harrowing + sowing with seed drill and light harrowing + one hoeing and 25 kg N through inorganic fertilizer (Urea) and 25 kg N through organic fertilizer through crop residue and *Leucaena* lopping (50% nitrogen through crop residue (byre waste) + 50% *Leucaena* lopping) + 12.5 kg P_2O_5 through fertilizer (SSP) found better for *rabi* sorghum grown on medium deep black soils
- For improving of soil fertility and higher yield of pearl millet, two harrowing before sowing and one weeding at 15-20 days and one hoeing at 30-35 days after sowing is recommended. Application of 25 kg N per ha through organics (FYM; tones and *Leucaena* loppings; 1.75 tonnes) and 25 kg N and 25 kg P_2O_5 ha^{-1} through fertilizer is recommended. Incorporation of crop residue after harvest of pearl millet is recommended.
- In blackgram-sorghum cropping sequence grown on medium deep black soils, the practice of reduced tillage followed by sowing of black gram for grain with 75% of RDF (19.0:38.0 N:P_2O_5 kg ha^{-1}) and hoeing at 3rd week is recommended. After harvest of blackgram, sowing of *rabi* sorghum along with 75% of RDF (38.0 :19.0 :25.0 N: P_2O_5: K_2O kg ha^{-1}) and two hoeing at 3rd and 5th week is recommended for getting higher yield, monetary returns and moisture use efficiency with maintaining soil health.

Cropping systems

- Early September sowing is recommended for *rabi* sorghum.
- Plant density between 50,000 to 1, 00,000 is recommended for safflower.
- In pearl millet, row spacing with 45 cm , clean cultivation upto 30 days and application of 50 kg N ha^{-1} is found better
- The continuous cropping of sorghum safflower and chickpea was not found economical. However, the crop

rotation like sorghum-chickpea, sorghum-safflower, and safflower-chickpea is recommended. For minimizing the pest problem, the crop rotations like sorghum-chickpea, sorghum-safflower is found better.

- Sowing of sunflower + pigeonpea intercropping (2:1) system in 24thmeteorological week is recommended. For delayed onset of monsoon up to 2nd fortnight of July, sunflower, pearlmillet and horse gram is recommended under dryland conditions. Sequence cropping under dryland conditions are pearlmillet-chickpea; blackgram/green gram – *rabi* sorghum.
- Fertilizer N economy: *Kharif*-cowpea for fodder with 12.5:25 N:P_2O_5 kg ha^{-1} followed by *rabi* sorghum with 25 kg N ha^{-1} is recommended for medium deep soils of dryland region
- Pearl millet + pigeonpea (2:1) or *Ber* (5 x 5 m) + Mothbean (8 rows) is recommended for shallow soils.
- For achieving higher yield and sustainability, planting of castor hybrid DCH-32 at 60 cm x 45 cm spacing with 50 kg N + 25 kg P_2O_5 ha^{-1} fertilizer dose in *Inceptisols* is recommended under dry land conditions.
- Sowing of sunflower (Cv. SS-56) in the 28th Meteorological Week (July 9 to 15) on ridges and furrows with 60 kg N + 30 kg P_2O_5 ha^{-1} fertilizer dose on *Inceptisols* is recommended for higher yields and sustainability under the dry land conditions.
- The application of crop residue i.e. chaffed sorghum byre waste, 5 t ha^{-1} (25 kg N) along with *Leucaena* loppings, 3.5 t ha^{-1} (25 kg N) as a green leaf manure is recommended for dryland *rabi* sorghum for best alternative to fertilizer urea and for improvement in yield and soil quality.
- Pearl millet + Pigeonpea (2:1) or (6:3) intercropping system is recommended for higher yields, monetary returns, land equivalent ratio and sustainability under dryland conditions. Sunflower + Pigeonpea (2:1) or (6:3) intercropping system is recommended for higher yields, monetary returns, land equivalent ratio and sustainability under dryland conditions.
- One hand weeding + three hoeing at an interval of 15 DAS or an application of Fluchoralin (Basalin) 45 EC at the rate 1kg a.i. per ha as preplant incorporation + one hoeing at 45 DAS is recommended for effective weed control, higher yield and returns in pigeonpea under dryland conditions.

Alternate land use systems

- Planting of drumstick (cv.PKM-2) at 8 x 8 m spacing in between two in-situ aonla plants planted at 8 x 8 m spacing and their after budded with *Krishna* cultivar and followed by sowing of intercrop of pearlmillet + pigeonpea (2:1) or sunflower + pigeonpea (2:1) intercropping system in between aonla + drumstick alley and removal of drumstick plants after fifth year when aonla plants start commercial yielding is recommended for sustainable yield and monetary returns on medium deep soils under dryland conditions.
- On medium deep black soils, planting of Aonla at 8 x 8 m; planting of drumstick in between two aonla plants in 8 m x 8 m alley; sowing of intercropping system pearlmillet + pigeonpea (2:1) or sunflower + pigeonpea (2:1) in between aonla + drumstick alley (Alley width 8 m); remove drumstick plants after fifth year when aonla plants start yielding and apply lifesaving/ protective irrigation to aonla + drumstick plants.

Technologies developed

Rainwater management

- Quantified tank silt application for higher productivity of *rabi* sorghum
- Ridges and furrows for *in-situ* moisture conservation
- Compartmental bunds are preferred where the infiltration rate of the soil is moderate and land slope is less. Before preparing the compartments, the land is prepared with primary tillage operation. Then with the help of bullock drawn *Baliram* plough / ridger or tractor drawn ridger, the compartments of varying sizes from 6 m x 6 m to 10 m x 10 m with 20-25 cm ridge height are prepared depending on the type of soil and slope. The cost of making compartment bunds is Rs. 1500 ha^{-1}. The main purpose of making compartment bunds is *in situ* conservation of rain water during *kharif,* to avoid soil erosion and to store more water in soil profile which is useful for *rabi* crops. The tractor drawn bund former developed by Department of FMPE and AICRP on FIM, MPKV, Rahuri is very useful in making compartment bunds of 2 x 6 m with effective field capacity of 4-5 ha per day.
- The farm pond is standardized. The excess runoff water is stored in these ponds. The ponds are lined with suitable lining materials like polythene film to prevent seepage losses. On the outer side slopes of the pond, the vegetation/ grasses are grown to avoid scouring. The harvested water is used for giving protective /supplemental irrigation to the crops at critical growth stages.

Cropping systems

Intercropping systems

- Pigeonpea + sunflower (1:2)
- Pigeonpea + pearlmillet (1:2)
- Pigeonpea + soybean (2:4 or 1:6)
- Pigeonpea + blackgram (1:3)
- Pigeonpea + greengram (1:3)

- Pigeonpea + bajara fodder (1:3)
- Sorghum + cowpea (4:4 and 6:6)
- Chickpea + safflower (2:4)
- Pearlmillet + sunflower (2:1 or 2:2)

Double cropping systems

- Blackgram - *rabi* sorghum
- Greengram - *rabi* sorghum
- Cowpea - *rabi* sorghum
- Blackgram - chickpea
- Greengram - chickpea
- Cowpea - chickpea
- Blackgram - safflower
- Greengram - safflower
- Cowpea - safflower

Sorghum cultivars according to soil depths

- Shallow soils (upto 30 cm): Selection-3, Phule Anuradha
- Medium soils (upto 60 cm): Phule Maulee, Phule Suchitra
- Deep soils (60 cm and above): Phule Vasudha, Phule Yashoda

Nutrient management

- Potash application in pearl millet and *rabi* sorghum for drought mitigation: It involves seed treatment with *azetobactor* @ 25 g kg^{-1} of seed before sowing and application of 50 kg N + 25 kg P_2O_5 + 25 kg K_2O ha^{-1} at the time of sowing on light to medium soil

Integrated nutrient management practices

Crop	INM Practice
Pigeonpea	Recommended dose of fertilizers (25 : 50 :0 N:P:K kg/ha) along with 5 t FYM + seed treatment with 25 g *Rhizobium* + 25 g PSB / kg seed; OR Application of 25 kg P through decomposed press mud cake + 25 kg P and 25 kg N through chemical fertilizer + seed treatment with 25 g *Rhizobium* + 25 gm SB/kg seed
Pearlmillet	Recommended dose of fertilizers (50 : 25 :25 N:P:K kg/ha) along with 5 t FYM + seed treatment with 25 g *Azospirillium* + 25 g PSB + 6 g Metalaxil 35 SD per kg seed for control of ergot disease. OR Application of 25 kg N ha^{-1} through organic (FYM @ 5 t and *Leucaena* loppings @ 1.75 t / ha) and 25 kg N + 25 kg P_2O_5 through fertilizer.
Sunflower	Recommended dose of fertilizers (50 : 25 :25 N:P:K kg/ha) along with 2.5 t FYM + seed treatment with 25 g *Azotobacter* + 25 g PSB + 5 g Emadochloprid 70 wp per kg seed for control of bud necrosis.
Blackgram, Greengram, Cowpea	Recommended dose of chemical fertilizers 25 : 50 N:P kg/ha along with 5 t FYM + seed treatment with 25 g *Rhizobium* + 25 g PSB + 5 g *Trichoderm*a per kg seed
Rabi sorghum	Recommended dose of fertilizers (50 : 25 :25 N:P:K kg/ha) along with 5 t FYM + seed treatment with 25 g *Azotobacter* + 25 g PSB + 4 g sulphur per kg seed OR 25 kg N through inorganic fertilizer (urea) and 25 kg N through organic fertilizer through crop residue and *Leucaena* lopping (50% nitrogen through crop residue (byre waste) + 50% *Leucaena* lopping) + 12.5 kg P_2O_5 through fertilizer (SSP) Application of 50 kg N per ha to through *Leucaena* loppings (25 kg N per ha) + urea (25 kg N per ha) or FYM (25 kg N per ha) + urea (25 kg N per ha) or *Leucaena* loppings (50 kg N per ha)
Chickpea	Recommended dose of chemical fertilizers (25:50:30 N:P:K kg/ha) along with 5 t FYM + seed treatment with 25 g *Rhizobium* + 25 g PSB + 5 g *Trichoderma* per kg seed
Safflower	Recommended dose of chemical fertilizers (50:25 N:P kg/ha) along with 5 t FYM + seed treatment with 25 g *Azotobactor* + 25 g PSB + 5 g *Trichoderma* per kg seed

Foliar nutrition

- Chickpea: Foliar spray with 1% KNO_3 at 30 DAS, 2% DAP at 45 DAS and 19:19:19 at 45 DAS and 55 DAS
- In zinc deficit soils, foliar spray of 0.5% zinc sulphate at 45 DAS

Energy management

- Two bowl ferti seed drill for efficient sowing of rainfed crops: The beam, handle and types of two-bowl ferti-seed drill are made by using *Acacia* wood. The seed and fertilizer bowls are made up of teak wood. This is attached to the yoke by means of beam and operated by a pair of bullocks and two labour. One person will place the seed in one bowl while driving the bullock and another person drops fertilizer in another bowl. It is used for line sowing of rainfed crops like sorghum, sunflower, safflower, pearl millet and pulses. The fertilizer is placed 3-4 cm below and 2-3 cm apart from the line of the seed. The improved ferti-seed drill costs Rs.2000 per piece. Effective field capacity for sowing of different crops is one ha per day. The operational cost is Rs. 1000 ha^{-1}.
- Cycle hoe: Cycle hoe consists of a steel hoe attached to a cycle wheel. This has a steel handle for steering the hoe while in operations. This is operated by one labour. It has simple design and easy to operate and maintain. Depending on the spacing of the crop, the length of the blade can be suitably changed. The cost of a cycle hoe is Rs. 1500/-. The

hoeing operation can be performed at any stage of the crop. Recommended hoeing in the *rabi* sorghum at 3rd, 5th and 8th week after sowing can be performed effectively.

- Bullock drawn multipurpose Phule Sheti Yantra for scarcity Zone of Maharashtra
- Energy Management for *rabi* sorghum grown on medium deep black soils: One harrowing + sowing with seed drill and light harrowing + one hoeing and 25 kg N through inorganic fertilizer (Urea) and 25 kg N through organic fertilizer through crop residue and *Leucaena* lopping (50% nitrogen through crop residue (byre waste) + 50% *Leucaena* lopping) + 12.5 kg P_2O_5 through fertilizer (SSP) is recommended for *rabi* sorghum grown on medium deep black soils in scarcity zone of Maharashtra for getting higher yield and monetary returns with minimum energy use and maintaining soil fertility.
- Growing of blackgram-sorghum cropping sequence on medium deep black soils in scarcity zone of Maharashtra for getting higher yield, monetary returns and moisture use efficiency with maintaining soil health, the following technology of reduced tillage is recommended.
- Harrowing to be done during onset of monsoon, sowing of black gram for green manuring or grain with ferti-seed drill (75% of RDF i.e., 19:38 N:P_2O_5 kg ha^{-1}) and subsequently light harrowing + hoeing at 3rd week after sowing of black gram. Then harrowing after harvest stage of black gram and sowing of *rabi* sorghum with ferti-seed drill (75% of RDF i.e., 38:19:25 N: P_2O_5: K_2O kg ha^{-1}) subsequent to light harrowing. Then two hoeing at 3rd and 5th week after sowing of *rabi* sorghum and harvesting of *rabi* sorghum above ground level.
- Spraying of 1% Potassium Nitrate (KNO_3) or water soluble NPK fertilizer 19:19:19 or DAP at 35 and 55 days after sowing along with recommended dose of fertilizer (50:25:25 N:P_2O_5:K_2O kg ha^{-1}) is recommended for mitigation of drought and management of dry spell for getting higher yield of *rabi* sorghum in medium deep black soils of scarcity zone of Maharashtra.
- Practicing of minimum tillage (one harrowing + sowing with seed drill and light harrowing + one hoeing) and nutrient management by application of 25 kg N ha^{-1} through urea + 25 kg N ha^{-1} through organics (50% crop residue + 50 % green Leucaena loppings) + 12.5 kg P_2O_5 ha^{-1} through single super phosphate to *rabi* sorghum for improving soil organic carbon stock (SOC) and carbon sequestration in deep black soils.

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)

- Pearl millet (Adishakti, Dhanshakti), fingermillet (Phule Nachani, COPN-942), groundnut (Phule Bharati, Phule Unnati), castor (Aruna, Girija), pigeonpea (Rajeshwari, BDN-708), horsegram (Phule Sakas), greengram (Vaibhav, Phule Chetak, Utkarshya), blackgram (TPU-1, TPU-4), cowpea (Phule Sonali, Vithai), sunflower (Phule Bhaskar, Bhanu) and mothbean (Phule Sarita, MBS-27)
- Intercropping systems: sunflower + pigeonpea (2:1), pearl millet + pigeonpea (2:1), clusterbean + pigeonpea (2:1), castor + pigeonpea (1:2), pigeonpea + greengram (1:3), pigeonpea + blackgram (1:3), pearlmillet + horsegram (2:1), pearl millet + mothbean (2:1), castor + clusterbean (1:2), pigeonpea + bajara fodder (1:3), cowpea + blackgram (2:2)

Delay by 4 weeks (2nd week of July)

- Pigeonpea, castor, mothbean, horsegram, cowpea
- Intercropping systems: pigeonpea + clusterbean (1:2), pigeonpea + coriander (1:2), pigeonpea + deel (1:2), sunflower + pigeonpea (2:1), pearlmillet + pigeonpea (2:1), cowpea + blackgram (2:2), pigeonpea + blackgram (1:3)

Delay by 6 weeks (4th week of July)

- Pearlmillet, castor, setaria spp., cowpea, sorghum fodder
- Intercropping systems: pigeonpea + clusterbean (1:2), sunflower + pigeonpea (2:1), pearl millet + pigeonpea (2:1), castor + pigeonpea (1:2), pigeonpea + coriander (1:2).

Delay by 8 weeks (2nd week of August)

- Sunflower, pigeonpea, greengram, blackgram, castor, pearlmillet, cowpea
- *Kharif* – fallow and during *rabi- rabi* sorghum, safflower, sunflower, chickpea
- *Kharif* – fallow and during *rabi*, strip cropping of chickpea + safflower (6:3); strip cropping of *rabi* sorghum + chickpea (6:3), *rabi* sorghum + cowpea (4:4 and 6:6)

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

Early season drought

- Resowing in case of poor germination
- Thinning in small seeded crops which are closely planted
- During *kharif* to conserve rainwater, make ridge and furrows, compartmental bunding and tied ridges followed by regular sowing of *rabi* crops.

Mid-season drought

- Take up repeated interculture operation i.e., hoeing for removing weeds and create dust mulching to conserve soil moisture
- Opening of alternate dead furrows in the sole *kharif* crops and for pigeonpea, opening of furrow 30 DAS for water/ moisture conservation.
- Foliar spray of 2% urea after receipt of rainfall
- Foliar spray of 1% KNO_3 at 30 DAS and 2% DAP in chickpea at 45 DAS
- Foliar spray 19:19:19 at 45 and 55 DAS in pulses
- Thinning by removing every third row in *rabi* sorghum
- Provide supplemental / life saving irrigation (4 cm depth) with harvested rainwater in ponds by adopting micro-irrigation (sprinklers) wherever possible
- Foliar spray of 8 % Kaolin in all *rabi* crops to minimize evapotranspiration losses.
- Prepare shallow furrow while hoeing by tying ropes to prongs, which will provide soil support to plants and conserve soil moisture
- Adopt surface mulching with crop residue or tree loppings of glyricidia wherever possible.
- If farm waste is not available, form a thin layer of soil mulch with blade harrow to avoid cracks
- In medium to deep black soils in *rabi* cropping areas, close the soil cracks by deep intercultivation in *rabi* sorghum and safflower

Terminal drought

- Provide life saving or supplemental irrigation through harvested rainwater from farm pond and other resources if available
- Harvest the *kharif* crops at physiological maturity with some realizable yield or harvest for fodder and prepare for *rabi* sowing of sorghum, chickpea, linseed, safflower in double cropped areas.
- Removal of lower leaves in standing crop to reduce moisture competition.
- Ratoon maize or pearlmillet or adopt relay crops as chickpea, safflower, *rabi* sorghum and sunflower with minimum tillage after soybean in medium to deep black soils or take up contingency crops (horsegram/cowpea) or dual purpose forage crops on receipt of showers under receding soil moisture conditions

For *rabi* planning

Suggested crops and varieties for delayed season (first fortnight of September)

- *Rabi* sorghum (Phule Anuradha), cowpea (Phule Pandhari, Phule Sonali)
- Chickpea (Vijay, Digvijay, Vikram), sunflower (Phule Bhaskar) and Safflower

Agroforestry systems

- Agro-horti systems: Aonla + pearlmillet + pigeonpea (2:1) or sunflower + pigeonpea (2:1); aonla + drumstick alley (alley width 8 m) and remove the drumstick after fifth year when aonla plant starts yielding.

Crop	Spacing	Variety
Aonla	8 m x 8 m	Krishna
Drumstick	4 m x 4 m	PKM 2

- Alternate land use system for shallow soils: Ber (5 m x 5 m) + mothbean 8 rows are recommended
- Horti-pastoral systems: mango + drumstick + stylo; mango + custard apple + stylo

Crop	Spacing	Variety
Aonla	8 m x 8 m	Narendra -7
Mango	10 m x 10 m	Keshar
Drumstick	4 m x 4 m	PKM 2
Custard apple	4 m x 4 m	Balanagar, Phule Purandar
Stylo	30 cm	RS 95, Phule Kranti

Technologies upscaled in convergence with various programmes

The rainwater management technologies viz., compartmental bunding and ridges and furrow method of *in-situ* moisture conservation were upscaled through State Department of Agriculture. The farm pond technology implemented and upscaled in farmers field through special mission implemented by State Department of Agriculture *'Magel tyala Shet Tale'* (Farm pond who demand), *Shet Tale Astarikaran* (Lining for farm pond), National Horticultural Mission project.

The tractor drawn compartmental bund former required for preparation of compartmental bunds for *in-situ* moisture conservation was developed by AICRP on Farm Implements and Department of FMP, MPKV, Rahuri based on the feedback given by Operational Research Project of AICRPDA, Solapur. The subsidy has been provided for purchase of different implements through Farm Mechanization Scheme under RKVY. Also theustom hiring of farm implements is being upscaled through Implements Bank (*Avajare* Bank) scheme under RKVY project. The flagship programme of State Government *'Jalyukt Shivar'* is focussed on water conservation activities and it includes the recommendation given by AICRPDA Centre regarding desilting of cement nala bunds for maintaining its storage life.

The recommended package of practices for cereal, oilseed and pulse crops were demonstrated by the State Department of Agriculture under National Food Security Mission programme. Also, the rainfed technologies developed under AICRPDA Centre are included in the package of practices under Nanaji Deshmukh Krishi Sanjivani Prakalp Project on Climate Resilient Agriculture (POCRA) funded by World Bank and implemented by State Department of Agriculture being implemented in 5142 villages located in 15 districts of Marathwada, Vidarbha and North Maharashtra.

The training to the farmers and officials of project implementing agencies regarding AICRPDA technologies are being given through '*Sheti Shala'* component of NFSM. The theme-wise Skill Training of Rural Youth (STRY) were organised by ATMA, Solapur in association with State Agricultural Management and Extension Training Institute (SAMETI), Maharashtra and National Institute of Agriculture Extension Management (MANAGE).

All technologies under rainwater management, crops and cropping systems, integrated nutrient management, participatory varietal selection/crop improvement, energy management theme were published in different leaflets / folders / local language newspapers as well as Krishi Diary of Mahatma Phule Krishi Vidyapeeth (*Krishi Dainandini* every year) and the same technologies were demonstrated and upscaled in farmer's field in collaboration with KVKs, ATMA, State Department of Agriculture and NGOs.

District wise contingency plan and various drought proofing action plans in the domain agro-climatic zones of the centre were upscaled during 2005 and 2017 funded by Department of Agriculture and Cooperation, Ministry of Agriculture and Farmers' Welfare, Govt. of India through CRIDA, Hyderabad. These were implemented in the state with the help of Maharashtra State Department of Agriculture. The centre, in collaboration with AICRP on Agrometeorology issues weekly weather based agro-advisories to the 70,000 farmers regarding climate situation and real time contingency measures that has to be followed and published in local newspapers, issued messages in different WhatsApp group of farmers of NICRA villages, OFR villages, etc. in domain districts (Solapur, Ahmednagar, Sangli, Satara, Pune, Dhule, Jalgaon, Nandurbar, Kolhapur).

Alternate land use management practices, viz, intercropping in custard apple and aonla, was upscaled through NHM scheme. The SHG's and FPO operating at village level helped in upscaling of dryland technologies. All the AICRPDA technologies were evaluated and upscaled through front line demonstrations in farmers field, organised field day, farmers rallies, training to stake holders etc., in the domain area through KVK's of SAU's, ATMA and other line departments operating in the zone.

Potash fertilizer management in dryland crops of Scarcity Zone of Maharashtra project funded by Indian Potash Institute, New Delhi implemented under AICRPDA developed different technologies *viz.,* i) Application of 20 kg K_2O for blackgram followed 50 kg K_2O for *rabi* sorghum, ii) Application of 50 kg K_2O for pearlmillet followed 20 kg K_2O for chickpea iii) Application of 50 kg K_2O for pearlmillet followed 20 kg K_2O for safflower found suitable for increasing the yield by 15 to 20% over recommended dose of potash application and sustaining the potassium status in soil. The upscaling, assessment and refinement of AICRPDA technologies has been done through AICRPDA-Operational Research Project implemented in six villages of Solapur, Sangli and Satara district of Maharashtra state.

Tank silt as an organic amendment for improving soil and water productivity is upscaled through the FPARP project funded by Ministry of Water Resources, New Delhi through ICAR-CRIDA, Hyderabad in five villages of Solapur district. This resulted in increase in the yield of *rabi* sorghum by 20-25 per cent over farmers practice (without tank silt application). The early maturing (95 days) horsegram genotype Phule Sakas as compared to ruling varieties *viz*; Man (115 days) and Sina (130 days) developed at AICRPDA, Solapur center in collaboration with AICRP on Arid Legumes is being upscaled through seed production programme of university and FLDs.

Under the ICAR-CRIDA funded NATP RNPS-2 Project implemented at Village–Wadala of North Solapur Taluk in Solapur District of Maharashtra (2000-2005), regional scale watershed plan and methodologies for identification of critical areas for prioritized land treatment in the watershed was developed for nutritious cereal production. Under the ICAR-CRIDA funded NATP TAR-IVLP Project (1996-2003), Technology Assessment and Refinement was carried out through Institution-Village Linkage Programme at Village Ratanjan of Barshi, Solapur and demonstrated that sustainability in rural livelihood of dry land areas can be achieved through improved crop management as well as with interventions of animal and poultry birds. The NWDPRA Projects (1999-2001) funded by NABARD implemented at Gulpoli & Turk Pimpari, Tal.Barshi, Dist.Solapur, upscaled the technologies *viz.,* for better germination and production of *rabi* sorghum on sodic soil. Around 7.5 t ha^{-1} FYM + 15 t ha^{-1} *murum* should be applied and mixed with upper soil layer and soil health management for *rabi* sorghum with 25 kg N ha^{-1} through sorghum byre waste + 25 kg N ha^{-1} urea for saving of 50 per cent chemical fertilizer (urea). Short duration legumes (cowpea, greengram, etc.) can be used successfully as green manure crop for dryland *rabi* sorghum technology and is upscaled through ICAR Cess funded Ad-hoc project (1998-2002).

The Custom Hiring Centre (CHC) for farm implements/ machinery in Narotewadi village of North Solapur is established in the year 2011 by AICRPDA Centre, Solapur under 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. Also the real time contingency measures are being upscaled in NICRA villages. It is necessary to upscale through SHGs, FPOs, NGOs, etc. for getting higher prices by exporting or processing the farm produce.

Impact of dryland technologies

The practice of making compartment bunds during *kharif* season for *in-situ* moisture conservation conserved 35% more moisture than farmers practice (two harrowing only) and increased grain yield of *rabi* sorghum to the tune of 2.0 q ha^{-1}.The net returns of Rs.9192, B:C ratio of 1.63 and RWUE of 8.43 kg $ha^{-1}mm^{-1}$ were observed under compartment bunding compared to farmers' practice (Rs.5240, 1.43 and 6.84 kg $ha^{-1}mm^{-1}$). The practice is widely adopted in 20% of *rabi* sorghum grown area in Solapur district. The compartment bunding was adopted by Govt. of Maharashtra and implemented with government cost on wide scale in dryland areas. This was more and widely accepted programme by the farmers. The practice of ridges and furrows during *kharif* for *in-situ* moisture conservation conserves 45% more moisture than farmers' practice (two harrowing only) and retains it for longer period (up to 60 days) and increases *rabi* sorghum yield (1091 kg ha^{-1}) by 53%.

The farm ponds are useful in harvesting excess runoff and the harvested water can be used for supplemental irrigation / protective irrigation to crops / orchards during dry spell or after rainy season. The productivity and income of rainfed crops provided with single critical/supplemental irrigation with harvested water was doubled. The yield, net returns and B:C ratio of chickpea irrigated with harvested rainwater were 1021 kg ha^{-1}, Rs. 19053, 1.52 respectively compared to chickpea without irrigation (695 kg ha^{-1}, Rs. 3919 and 1.11). The RWUE for chickpea with irrigation was 17.01 and without irrigation was 11.58 kg $ha^{-1}mm^{-1}$. The sustainable yield index (SYI) for chickpea with irrigation was 1123.4 and without irrigation was 794.8.

Instead of keeping deep black soil fallow in *kharif,* short duration pulse crop viz., blackgram / greengram / cowpea are grown followed by *rabi* sorghum. Under normal rainfall conditions, the pulses are grown for grain purpose and under abnormal conditions pulses are grown either for fodder or green manuring. It improves the soil fertility and saving of 25 % nitrogen recommended dose for sorghum. There was an increase in net returns by Rs.38928/ ha with B:C ratio of 2.03 compared to *rabi* sorghum alone (Rs.29775 and B:C ratio 1.79). This practice is adopted on 20 per cent of *rabi* sorghum area in domain districts.

The improved sunflower + pigeonpea (2:1) system has been adopted in 30% area under sunflower in Solapur district (6500 ha), while pearl millet + pigeonpea (2:1) was adopted in about 10 % area under pearl millet in Ahmednagar, Pune and Dhule districts (80000 ha) in Maharashtra. There is a lot of scope for enhancing the area under improved intercropping systems due to risk minimization and attaining higher monetary returns. The improved intercropping systems gave about 30% increase in productivity and net returns compared to farmers practice. The net returns were Rs.11313 ha^{-1} from sunflower + pigeonpea and Rs.10580 ha^{-1} from pearl millet + pigeonpea systems with BC ratio of 1.76 and 1.74 respectively. In sunflower, net returns of Rs.6000 with B:C ratio of 1.18 and in pearl millet net returns of Rs.6500 with B:C ratio of 1.20 were observed.

Seed treatment with *azotobactor* @ 25 g per kg of seed before sowing and application of 50 kg N + 25 kg P_2O_5 + 25 kg K_2O ha^{-1} at the time of sowing on light to medium soil can mitigate drought severity, 38% increase in grain yield of *rabi* sorghum over no application of potash with 3.48 B:C ratio and 20% increase in grain yield of pearl millet over no application of potash with B:C ratio of 2.10. Net returns and B:C ratio of potash applied to pearl millet and *rabi* sorghum were Rs. 8893 and Rs. 12320 respectively compared to farmers' practice of pearl millet (Rs. 6324) and *rabi* sorghum (Rs. 9870). This improved practice has been adopted in 10 to 15% of pearl millet and *rabi* sorghum area in domain districts.

The suitable sorghum varieties for shallow soils (upto 30 cm) are Selection-3, Phule Anuradha, medium soils (upto 60 cm) are Phule Maulee, Phule Suchitra and deep soils (60 cm and above) are Phule Vasudha, Phule Yashoda. The yield increase of Selection-3, Phule Anuradha (shallow soils) was 15%, Phule Maulee, Phule Suchitra (medium soils) was 15-20% and Phule Vasudha, Phule Yashoda (deep soils)was 25-30% over local variety Dagadi. The net returns and B:C ratio of Selection-3, Phule Anuradha (shallow soils) were Rs.9890 and 2.1, Phule Maulee, Phule Suchitra (medium soils) were Rs.11890 and 2.2 and Phule Vasudha, Phule Yashoda (deep soils) were Rs.10560 and 2.7 over local variety Dagadi. Adoption in shallow soils was 15-20%, medium soils was 30-35 and deep soils was 35-40% in domain area.

One harrowing + sowing with seed drill and light harrowing + one hoeing and 25 kg N through inorganic fertilizer (urea) and 25 kg N through organic fertilizer through crop residue and *Leucaena* loppings (50% nitrogen through crop residue (byre waste) + 50% *Leucaena* lopping) + 12.5 kg P_2O_5 through fertilizer (SSP) is recommended for *rabi* sorghum grown on medium deep black soils in scarcity zone of Maharashtra for getting higher yield and monetary returns with minimum energy use and maintaining soil fertility. The improved tillage and nutrient management practice gives grain yield of 1706 kg ha^{-1} and stover yield of 4084 kg ha^{-1} while conventional tillage gives grain yield of 1350 kg ha^{-1} and stover yield of 3429 kg ha^{-1}. The net returns and B:C ratio with improved technology were Rs. 64879 and 4.21 compared to farmers' practice (Rs. 45854 and 3.18). This improved practice has been adopted in 15 to 20% of *rabi* sorghum area in domain districts.

Application of 25 kg N ha^{-1} through chaffed sorghum byre waste (5 t) + 25 kg N ha^{l} through *Leucaena* loppings (3.5 t) is recommended for rainfall zone-IV of scarcity zone of Maharashtra for improvement in yield of *rabi* sorghum and soil quality. The improved technology gives 12.38 q ha^{-1} grain yield and 33.47 q ha^{-1} stover yield and they were higher than RDF of 50 kg N ha^{-1} through urea (11.82 and 32.96 q ha^{-1} respectively). However, significant improvement in the soil fertility at harvest of *rabi* sorghum would be more beneficial for sustainable productivity of sorghum with improvement in soil health. This integrated nutrient management has been adopted in 15 to 20% of sorghum area in domain districts.

For improving of soil fertility and higher yield of pearl millet, two harrowing before sowing and one weeding at 15-20 days and one hoeing at 30-35 days after sowing and application of 25 kg N per ha through organics (FYM 5 t ha^{-1} and *Leucaena* loppings 1.75 t ha^{-1}) and 25 kg N and 25 kg P_2O_5 ha^{-1} through fertilizer is recommended. It gives higher grain yield of pearl millet (835 kg ha^{-1}) over 100% organic N (620 kg ha^{-1}) and gave maximum net profit of Rs. 3982 ha^{-1} over 100% organic N (Rs. 5240 ha^{-1}). This integrated nutrient management has been adopted in 15 to 20% of sorghum area in domain districts.

Integrated farming system (IFS) model of 1.0 hectare rainfed area comprising 50% crop component, 40% horticulture component, 5% animal component and 5% farm pond is recommended for economic viability of small farmers under Scarcity Zone of Maharashtra. The average net returns from IFS were Rs. 76664 with B:C ratio of 2.0 compared to *rabi* sorghum alone (Rs. 14928 with 1.5 B:C ratio). In IFS, the contribution of crop component was 11%, horticulture component was 10% and animal component was 79% to the net returns.

Application of 25 kg N ha^{-1} through FYM @ 5.0 t ha^{-1} + 25 kg N through urea + 25 kg P_2O_5 ha^{-1} through single super phosphate is recommended for maintaining soil health, higher grain and stover yields and monetary returns of *rabi* sorghum grown on medium deep black soil in scarcity zone of western Maharashtra. The improved technology gave maximum grain yield (1448 kg ha^{-1}) and stover yield (3688 kg ha^{-1}) with higher net returns (Rs.30066 ha^{-1}) compared to farmers' practice (833 kg grain yield ha^{-1}, Rs.14254 of net returns). This helps in maintaining soil health and reduces 50% of nitrogen from chemical fertilizer dose. This improved practice has been adopted in 15 to 20% of *rabi* sorghum grown area in domain districts.

The horse gram genotype (Phule Sakas) is early maturing (95 days) as compared to ruling varieties *viz*; Man (115 days) and Sina (130 days). The variety is having bolder seed with brown colour. The culture is non shattering type, being erect in habit pods, do not touch to the ground and prevent damage to the pods. The genotype is having high protein (22.09%) and less tannin (1.14%) content. The culture is moderately resistant to yellow mosaic virus and minimum and comparable incidence of white flies (1.18 flies per plant).

The average seed yield is 1025 kg ha^{-1} in station and University Multilocation trials. The culture (1025 kg ha^{-1}) has shown 42.55% increased seed yield over the early check Man (719 kg ha^{-1}) and 31.41% over the second check Sina (780 kg ha^{-1}). Whereas, at national level, it has given 19.26% increase seed yield over the national check AK-42. The net returns were Rs. 8870 compared to Man (Rs. 6280) and Sina (Rs. 6580). It was adopted in 25% area of millets in domain district. The location specific constants K, a, b and d in intensity -frequency-duration relationship was developed for Solapur, Pandharpur and Jalgaon region and used for estimation of runoff. The estimation of runoff is required for design of soil and water conservation structures.

Timely operations of seeding and fertilizer application are carried out simultaneously with the help of bullock drawn two bowl ferti seed drill. This improves fertilizer use efficiency and enhances the productivity of crops up to 20%. The cycle hoe performs efficiently on the farmer's fields with a reduction in drudgery for hoeing operation. It is also convenient for women to operate. One labour can cover one acre/day. The bullock drawn multi-purpose Phule seed drill implement can be used for sowing, harrowing and also as a cultivator and are suitable for all soil types and crops, and even for sowing of intercrops. By using this implement, saving of one labour and timely and efficient agricultural operation is ensured. Further, upscaling of this practice can be done in different districts with similar agro ecological features through more extension efforts and linkage with line departments, and through demonstrations by ATMA, KVKs and NGOs etc.

Way forward

- The research should be focussed on crop and cropping systems, resource management, evaluation of improved dryland varieties, integrated nutrient management, integrated farming system and arid legumes *viz.*, clusterbean, rajma bean, cowpea, pigeonpea, horsegram, mothbean and pearl millet.
- Development of new drudgery reduction implements for the rainfed farmers especially for *rabi* sorghum, pigeonpea, sunflower, pearl millet and safflower are also needed.
- Development of new technologies related to sequestration of atmospheric carbon, soil health management are also essential.
- Mechanization in dryland agriculture, development of hand tools and equipment for drudgery reduction for small and marginal farmers are also required.
- Development of Integrated farming system module for small, marginal and medium land holdings.
- Development of new technologies for dryland fruit crops and vegetables especially for ber, aonla, tamarind, mango, custard apple, drumstick, coriander, amaranthus, ajwain, etc.