SATSA Mukhapatra - Annual Technical Issue **27** : 2023 ISSN 0971-975X **Invited Paper**

Sustainable Intensification of Crop Production under the Drought Condition

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((Received : January 02, 2023; Revised : January 31, 2023; Accepted : February 04, 2023)

ABSTRACT

India has been vulnerable to natural calamities which have left behind death and destruction with huge impact on the developing economy of the country. With the constraints of climate change accompanied by continually increasing demand for food has compelled the world's farmers to produce more food per hectare with less water, and with fewer agrochemical inputs if possible. This is achieved by sustainable intensification through efficient use of inputs, emphasizing technologies like high-tech precision agriculture for field crops, alternative-wetting-and-drying for irrigated rice production, and integrated pest and nutrient management to reduce and optimize the use of agrochemical inputs.

Among the worst climate change impacts, drought is one type of natural hazard that will have a detrimental impact on people or the environment. Droughts have complicated causes since they depend on both the hydrologic processes that provide moisture to the atmosphere and the atmosphere itself. Drought mitigation measures aim to lessen the harmful consequences of drought on people, livelihoods, and other environmental elements. The drought mitigation practices include pre-disaster, during the disaster, and post-disaster practices coupled with crop intensification and water management practices.

Keywords : Drought, Impacts of climate change, Impacts on economy, Mitigation practices, Crop intensification and water management.

Introduction :

The southwest monsoon brings heavy rainfall tothe Indian subcontinent with a long-term (1961-2010) average of 881 mm in a span of four months (June to September; also called Indian summer-monsoon rainfall). The monsoon is the lifeline of Indian agriculture and the economy of the country. A failure of the monsoon, or even a deficit of rain across the country, may bring misery and instability to the country's food production.The pattern of onset and withdrawal of the monsoon leaves northwest India with a shorter rainy period compared to the southwest and the northeast of India which receive higher rainfall over a longer rainy season. The annual total deficit rainfall years (24) exceeded the total excess rainfall years (22) during 1961-2016 in northwest India, the food basket of the country, which had implications for the *kharif* crops (Saxena and Mathur, 2018). Nearly 70% of India's

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crop land annually receives 750-2000 mm of rainfall. Irregularities in rainfall in these areas such as late-onset, long breaks, and early withdrawal of monsoon make these areas vulnerable to mild or severe droughts (Shaw et al., 2005; Prabhakar and Shaw., 2008). Droughts account for 15% of natural disasters, although a large number of deaths due to droughts have been reported globally, mostly in developing countries (WMO, 2021). The effect of severe droughts was estimated to have reduced India's gross domestic product by 2 to 5 percent over a period of 10 years (1998 to 2017; UNDRR, 2021). Monitoring of agricultural drought has been a prime research activity in both India and abroad. The use of space technology has revolutionized drought assessment and monitoring in recent years (Figure 1).

Agricultural production is increasingly being challenged by the demand for food coupled with dwindling availability and quality of resources, accompanied by weather variability and climate change. This necessitates optimizing the inputs to maximize production and maintain the output over a period of time. Promoting better root growth and enhancing the soil's fertility is one of the few efforts to make the agricultural production system less water- and fertilizer-intensive, with reduced seeds, fewer agrochemicals, and greater climate resilience. Sustainable intensification (SI) encompasses technologies of high-tech precision agriculture for field crops, alternate wetting, and drying for rice production, and integrated pest and nutrient management to reduce and optimize the use of agrochemicals. The SI seeks to transform the farmers to be least dependent on external inputs and to capitalize more effectively and efficiently on the natural resource base and its inherent capacities (Pretty et al., 2011).

Droughts as natural hazards :

According to the India Meteorological Department (IMD), drought is caused by a natural decrease in rainfall over an extended period of time, typically lasting a season or longer. The IMD defines drought in an area where the rainfall deficiency is e"26% of its long-term rainfall in that area (Shewale and Kumar, 2005). When the deficiency is between 26 to 50%, it is referred to as moderate, and >50% deficiency is called a severe drought. For the country as a whole, when the rainfall deficiency exceeds 10% of the Indian summer-monsoon rainfall and the area exceeds 20% of the total area of the plains in the country, it is considered a drought situation for the country. Factors like high temperatures, strong winds, and low relative humidity frequently accompany drought. Drought isalso classified as meteorological (lack of rainfall), hydrological (dryness in surface water storage), agricultural (lack of moisture in the root zone), and socioeconomic (shortage of water supply for socio-economic purposes). The final category is known as a water resources indicator, and the previous three are referred to as environmental indicators (Wilhite, 2000a).

Drought is a type of natural hazard (hazard is a natural process or phenomenon that may pose negative impacts on the economy, society, and ecology, and it includes both natural and human factors; United Nations International Strategy for Disaster Reduction that becomes worst with rising water demand. Droughts depend on both the hydrologic processes that provide moisture to the atmosphere and the atmosphere itself.Droughts set in when dry hydrologic conditions are established. Water is lost from top soil layers reducing the crop evapotranspiration rates, which, in turn, lowers the relative humidity of the atmosphere. Since a typical low-pressure system over an area may not reach its saturation over the long run, the less relative humidity there is, the less likely it is that it will rain unless enough moisture moves in from outside (Bravar and Kavvas, 1991). The onset of drought is a slow and gradual phenomenon and is difficult to forecast. Similarly, a drought frequently continues for a long time, even for years after termination. Therefore, the effects are non-structural and widespread, and quantifying the impact and providing aid becomes challenging compared to other natural hazards (Wilhite, 2000a). It is further complicated due to the fact that human activity can directly be responsible. A number of activities like deforestation, non-judicious use of water, erosion, unplanned and non-scientific farming practices may cause drought even under normal rainfall or non-limiting water availability.

Drought mitigation practices :

Practices for reducing the effects of drought are the pragmatic ways to ensure ecosystem resilience during the dry spells. It aims to minimize the adverse consequences of drought on people, livelihoods, and other environmental elements.Three most critical elements of drought mitigation are assessment, monitoring of drought's intensity and application of techniquesfor the mitigation. Based on the timing, the practices have three forms - pre-, through-, and post-disaster practices, and can be either of proactive or reactive measures(Buchanan-Smith, 2000). Based on the longevity,the mitigation can be operational (the beginning of drought and the time of its duration), short-term (before beginning in advance up to 5 years), and long-term (long perspective, up to 25 years) (Labêdzki, 2016). Mitigation, of course, can be local or institutional-based on the level of their adoption and stewardship.

Pre-disaster mitigation strategies :

Pre-disaster mitigation strategies refer to preparedness and mitigation measures. These are proactive. An increase in the frequency of droughts in many parts of the world hasprompted the improvementof drought preparedness and improvement of mitigation measures. In most of countries, soil conservation, watershed development, and forestry programmes include courses and actions aimed at these acts, as the mitigation is primarily related to integrated soil, water, and vegetation(forestry) management. The creation of an early warning system, expansion of water sources and water conservation measures, and crop insurance are typical examples of proactive initiatives.Increasing and sustainingwater supply, expanding irrigation facilities in full or partial (life-saving), maintaining vegetation cover, and educating and raising public awareness of themare common drought mitigation programmes (UNISDR, 2009). The best practicesinclude :

i. Dissemination of knowledge to the vulnerable groups through training on how seasonal forecasts and decision support tools can increase resilience, effective coping strategies, and preparation in vulnerable sectors

ii. Encouraging the adoption of risk-management practices through incentives and engaging the vulnerable groups in the national drought management policy

iii. Locating and sharing examples of effective interagency or inter-ministerial coordination in planning, reaction, mitigation, and monitoring of drought

iv. Assessing the potential for drought drills or exercises to improve institutional coordination for preparedness and response

v. Gathering and using local and customary knowledge to inform decision-making

vi. Ensuring links between science and issues of policy

Some of the preventive measures and preparedness plans for the mitigation of drought are mentioned below (Gupta *et al.,* 2011) :

1. Preventive measures: Development of dams/Reservoirs and wetlands; Watershed management; Rationing of water; Cattle management; Selection of crops for drought-prone areas; Land levelling and soil conservation techniques; Arrest deforestation and reduce fuelwood cutting; Alternate land use models for water sustainability; Checking migration and provide employment; Participatory programmes

2. Preparedness: Modification of cropping system; introduction of drought-resistant varieties; Rangeland management – improvement of grazing, protection of shrubs and trees; Improved irrigation and water storage facilities; Maintenance of vegetation cover to check soil evaporation; Improved animal husbandry

Mitigation practices during and after the drought :

These are reactive forms viz., emergency response and relief measures (most frequently followed), while other strategies could be low-interest loans and transportation subsidies for livestock and livestock feed, provision of food, transport of water, and wells for irrigation and public water supplies.The effectiveness of these practices increases when authorities, citizens, and communities are well-prepared to respond and well-equipped with critical infrastructure (Oduor *et al*., 2014; Omodanisi *et al.,* 2014). Traditional knowledge of how local people have survived prior droughts can aid in mitigating the drought or increase preparedness.Social media networks like Facebook, YouTube, and Twitter can be crucial instruments for knowledge dissemination. The use of geoinformatics needs a special mention here (Tang *et al*., 2015).

A number of approaches and initiatives for drought management have been taken by the Indian Government (GOI) over years. Currently, these are early warning and preparation, crisis management, medium- and long-term drought mitigation initiatives, and a larger use of cutting-edge technology and scientific techniques.A variety of Schemes/Programs have been developed over timefor the mitigation of medium- and long-term drought viz., Rashtriya Krishi Vikas Yojna (RKVY), Swarna-jayanthi Grameen Swarozgar

Yojana (SGSY), National Rural Drinking Water Programme (NRDWP), Integrated Watershed Management Programme (IWMP), Fodder & Feed Development Scheme, and the Mahatma Gandhi National Rural Employment Guarantee Scheme (MGNREGS).Moreover, numerous area development initiatives by State Governmentswith assistance from the GOI, such as the Rural Infrastructure Development Fund (RIDF) and the Backward Region Grant Fund (BRGF), have a significant impact on improving drought resilience. Overall, the operational framework for drought mitigation comprises (a) drought risk and vulnerability assessment, (b) forecasting and early warning, and (c) structural & non-structural measures including drought proofing programs/schemes, (d) awareness generation, (e) research & development and (f) community participation.

Crop intensification for drought mitigation :

Crop intensification is one of the techniques that is being used to imbibe climatic resilience in the agricultural system. Sustainable crop intensification aims to meet food security while maintaining environmental health. The system of crop intensification (SCI) has emerged in recent years in several Asian and African countries, improving the productivity and use efficiencies of land, water, labour, and capital resources for growing a wide range of crops. The ideas and practices of SCI have originated from experiences with the system of rice intensification (SRI). Major components of SRI are given in Figure 2.

The success stories of SRI in China's Sichuan province can be noted here. The area under SRI increased from 1133 ha in 2004 to 383,533 ha in 2012 with an average yield advantage of 1.7 t ha^{-1} compared to conventional rice cultivation. This equated to an additional 2.8 Tg of paddy produced by Sichuan farmers during this time period, with a 25% reduction in irrigation water used for rice production (Zheng *et al.*, 2013). The provincial data from 2006 and 2010, which were major drought years in Sichuan from 2004 to 2012, are particularly relevant here. The average yield advantage in SRI in drought years 2006 and 2010 was 1.8 t ha^{-1}, compared to the average SRI yield advantage of 1.6 t ha^{-1} in other normal rainfall years (Zheng *et al.,* 2013). Over two seasons, researchers at the Indian Agricultural Research Institute (IARI) evaluated an extrapolation of SRI methods to wheat cultivation (system of wheat intensification, SWI). The System of Wheat (SWI) cultivation at the Indian Agricultural Research Institute (IARI) gave a yield advantage of 30% in a normal year. In a year when both temperature and rainfall were adverse, the SWI yield fell by 12.5 percent, whereas yields fell by 18-31 percent in other conventional standard practices. A similar advantage was observed in trials comparing rice production results in normal vs. drought-stressed seasons in eastern India (Thakur *et al.,* 2015).

The theory and practice of SCI as with the experiences in SRI are shared with other technological innovationslike agroforestry, conservation agriculture, integrated pest management, and integrated range and livestock management.

The common elements involved in SCI crop management, which has marked similarities with SRI, can be summarized as follows (Abraham *et al.,* 2014) :

- Early establishment of plants to make them healthy and vibrant, and to conserve and nurture the root growth potential
- Reductions in crop density, allowing wider spacing, enabling plant to enjoy enough space in both upper and lower ground
- Enrichment of soil with organic matter, and ensuring good aeration in the soil to support a healthyroot growth and active soil biota
- Optimizing water application to maintain the most-favourable air-water ratio for roots and soilmicrobes, avoiding hypoxic condition

The SCI experiments in different crops across different countries are summarized below (Adhikari *et al.,* 2018) :

Crop	Country (state, province, or district)	Comparison yield (t/ha)	SCI yield (t/ha)	Comments	Source
Finger millet	India (Karnataka)	1.25-2.5 (3.75 max)	4.5-5.0 (6.25 max)	Indigenous farmer-developed system of cultivation (Guli Ragi)	Farmer information (Uphoff, 2006)
	Ethiopia (Tigray)	1.3	4.0-5.0	SCI methods developed before any knowledge of SCI	ISD data (Araya *et al.,* 2013)
	India (Uttarakhand)	1.5-1.8	2.4	Evidence of climate resilience	PSI data
	India (Odisha)	1.0-1.1	2.1-2.25	Evidence of climate resilience 2013 : 143 farmers; 2016 : 2259	PRAGATI data (Adhikari, 2016)
Wheat	India (Bihar)	2.0	4.6	2008/09: 278 PRAN farmers; 2015/2016: ~500,00 farmers (300,000 ha)	PRADAN data (Verma, 2013)
		2.25	3.87	86% increase in income/ha	Jeevika data (Behera *et al.,* 2013)

Crop	Country (state, province, or district)	Comparison yield (t/ha)	SCI yield (t/ha)	Comments	Source
	Nepal (Khailali and Dadeldhura)	3.4	6.5	Replicated trials, average for upland and lowland yields	Khadka and Raut (2012)
	Afghanistan	3.0	4.2	Farmer results under national FAO programme	FAO IPM programme data (Kabir Communi-cation)
	Mali (Timbuktu)	1.0-2.0	3.0-5.0	Farmer trials under Africare	Styger and Ibrahim (2009)
	India (IARI research)	5.42 (SRP)	7.44	Two years of experimental results at IARI, New Delhi	Dhar *et al.* (2016)
Maize	India (Him. Pradesh) India (Assam)	2.8 3.75-4.0	3.5 6.0-7.5	On-farm trials On-farm trials	PSI data Sesta Development Services, Guwahati, Assam, India
Sugarcane	India (Telangana)	80	99.5	On-farm trials	AgSri data (Gujja *et al.*, 2017)
	India (Odisha)	60-70	119	On-farm trials	
	India (Maharashtra)	70	96	On-farm trials	
	India (Uttar Pradesh)	61 [59]	68 [71]	On-farm trials [ratoon harvest]	

Crop	Country (state, province, or district)	Comparison yield (t/ha)	SCI yield (t/ha)	Comments	Source
	Kenya (Kakamega)	70	90-100	On-farm trials	AgSri data (Gujja *et al.*, 2017)
	Cuba	60-75	85-100	Modified SSI on-farm trials	R. Perez (personal communi-cation)
Tef	Ethiopia	1.6	2.8 (TIRR) 3.0-5.0 (STI)	Estimated TIRR area in 2016 was 1.1 million ha	ATA (2016)
Mustard	India (Bihar)	1.0	3.0	On-farm production	PRADAN (2012)
			4.0 (full use)		
	India (Mad. Pradesh)	1.2	2.73 (1.8-3.3)	On-farm trials	PSI data
Pulses	India (HP/UKD/MP)	46% averageincrease acrossseven pulses			PSI data
	India (Bihar)	56% increaseacross differentpulses (15,590 households)			Behera et al. (2013)
Vegetables	India (Bihar)	20% averageincrease in yield; 47% increase in net income/ha			Behera et al. (2013)

Crop intensification through crop diversification, cropping patterns, etc. has been in practice in drought-affected North-western Bangladesh, which has been documented by Orindi and Eriksen (2005) and Adger *et al.* (2003). The majority of farmers in this area have adopted crop diversification as a means to reduce the risk, which includes sugarcane, pulse andoilseed crops, vegetables, and fruit crops like mango, jujube, etc. Two crops are raised in the same field viz., rice and mango which acts as an option to minimize yield loss when drought sets inand adds economic benefits to the farmers. Some examples of crop diversification with rice as the main component are chickpea, mung bean, mustard, and linseed with varying levels of success and probability of adaptation (Habiba *et al.*, 2013).

Water management for sustainable crop intensification :

Irrigation plays a major role in crop intensification in developing countries, which necessitates strategic adjustments (Dubois, 2011). Improving water productivity can be achieved through water harvesting and is classified into three categories: macro-catchment (*ex-situ*), micro-catchment, and *in situ* systems (Biazin *et al.*, 2012). Macro-catchments collect water from a large area (Oweis and Hachum, 2006) and require water collection, conveyance, and storage structures. Micro-catchments collect water from a relatively small area; catchment and cropped areas are distinct but adjacent to each other (Hatibu *et al.,* 2006). *In situ* water harvesting systems are practices where rainfall water is captured and stored where it falls. These improve soil moisture by enhancing infiltration and reducing runoff and evaporation (Ngigi *et al.,* 2005). However, most of the literature considers micro-catchments as *in situ*water harvesting systems.However, integrating water harvesting with better soil, nutrient, and crop management approaches is the best option to increase water productivity andyields in small-scale agriculture (Rockstrom *et al.,* 2002).

Due to their tolerance to moisture deficit, cereals such as finger millet (*Eleusine coracana Gaertn.*) and legumes such as cowpea (*Vigna unguiculata (L.) Walp.*) and groundnut can be best suitable in drought-prone areas (Tadele, 2016). Cowpea is another crop with high tolerance to heat, limited moisture and low soil organic matter (Sanginga *et al.,* 2000). The seeds of finger millet contain important amino acids, particularly methionine which is deficient in the diets of hundreds of millions of poor people suitable under water-limited conditions. Because of their health benefits, some indigenous crops are also considered lifestyle crops. Finger- and pearl millets, for example, have anti-proliferative properties and may be useful in the prevention of cancer initiation (Chandrasekara and Shahidi, 2011).

Genetic approach :

Transgenic plants are becoming promising ways for improving drought tolerance traits in less time compared to traditional breeding programmes. In transgenic wheat, genes that confer drought tolerance and improve plant growth and survival have been identified. Various techniques such as marker-assisted breeding, quantitative trait locus mapping, and introgression from the wild gene pool are techniques to improve drought tolerance (Gupta *et al.,* 2017). Transgenic wheat transformed with a mutated transcription factor (HaHB4) from *Helianthus annuus* (sunflower), which is a member of the homeodomain-leucine zipper family (HD-Zip I), had increased its water use efficiency and yield (González *et al.,* 2019). Drought tolerance was demonstrated in transgenic wheat carrying a GmDREB1 gene from soybean under a ubiquitin promoter (Gao *et al.,* 2005). One major goal is to improve WUE so that plants can grow well under water stress. Water use efficiency could be improved by inserting genes for compatible osmolytes such as sugar and amino acids (Abebe *et al.,* 2003) or through over-expressionof the late embryogenic abundant proteins that provide dehydration tolerance.

Abscisic acid (ABA) aids plant drought tolerance by activating a variety of signalling mechanisms (Bücker-Neto *et al.,* 2017). Increased ABA induced a signalling pathway in guard cells, resulting in guard cell K+ outflow and reduced turgor pressure, ultimately causing stomata closure (Salazar *et al.,* 2015, Lim *et al.,* 2015). It reduced drought stress and increased wheat tolerance by increasing stem lengths and plant biomass while decreasing H_2O_2 and malondialdehyde (MDA) levels (Kapoor *et al.,* 2020).It was reported that there are distinct differences in functional characteristics among AREB-type transcription factors, and can be utilized for the development of drought-tolerant crops (Yoshida *et al.,* 2010). Considering both the overlapping and specific functions of these three AREB-type transcription factors, the combinations of genes and promoters can be optimized to appropriately meet the various needs of different crop varieties or according to levels of drought (Figure 3). Geda *et al.* (2019) attempted to incorporate drought tolerance in Indica rice by incorporating the *Arabidopsis* AtDREB1A gene via an *Agrobacterium*-mediated transgenic approach. Physiological studies on eight transgenic lines established that the introduced gene could bring higher levels of drought tolerance in rice. A list of a large number of drought-tolerant varieties which are cultivated in India can be found onthe Ministry of Agriculture & Farmers Welfare website.

Plant growth promoting rhizobacteria (PGPR) in drought tolerance :

The unique genetic makeup of bacteria living in the rhizosphere (*rhizobacteria*) is essential to the health and productivity of plants. Root-colonizing bacteria called plant growth-promoting rhizobacteria (PGPR) produce a variety of enzymes and metabolites that help plants withstand adverse environmental conditions (Figure 4). PGPR can be divided broadly into two classes : 1) ePGPR (extracellular PGPR), which includes*Agrobacterium, Azotobacter, Erwinia, Serratia, Bacillus*, etc., grow in the rhizosphere or in between cells of the root cortex; and 2) Intracellular PGPR (iPGPR), which includes *Azorhizobium, Mesorhizobium and Allorhizobium* (Naylor *et al.,* 2018). PGPR induces drought tolerance in crops by producing phytohormones, volatile compounds, ACC deaminase, osmolyte and exopolysaccharides and activating antioxidant activities. Phytohormones produced by rhizobacteria such as indole-3-acetic acid (IAA), gibberellin (GA), cytokinin, abscisic acid, and ethylene become important for promoting growth and development and assisting plants in escaping abiotic stress (Urano *et al.,* 2017). These are critical targets for engineering metabolic products that confer drought tolerance on crop plants (Wani *et al.,* 2010).The drought stress tolerance induced by rhizobacteria in the plant is in addition to the drought resistance genes that are present or absent in the plant.

Conclusions :

A paradigm shift in disaster management, or the transition “to ecosystem approach in climate change adaptation and disaster risk management,” is currently taking place around the world. It is now crucial to work on alternatives to systems for predicting droughts based on rainfall data. Strategic environmental evaluations must be used to evaluate the effects of local and global environmentally Sustainable Crop Intensification has emerged as a potential mitigation approach that is less resource hungry as well as sustainable in nature. However, since the concept of SCI as rather new, further research is required before its widescale adaptation. At the same time, techniques like SCI should be prioritised during policy making at an institutional level for successful dissemination of these techniques among farmers.

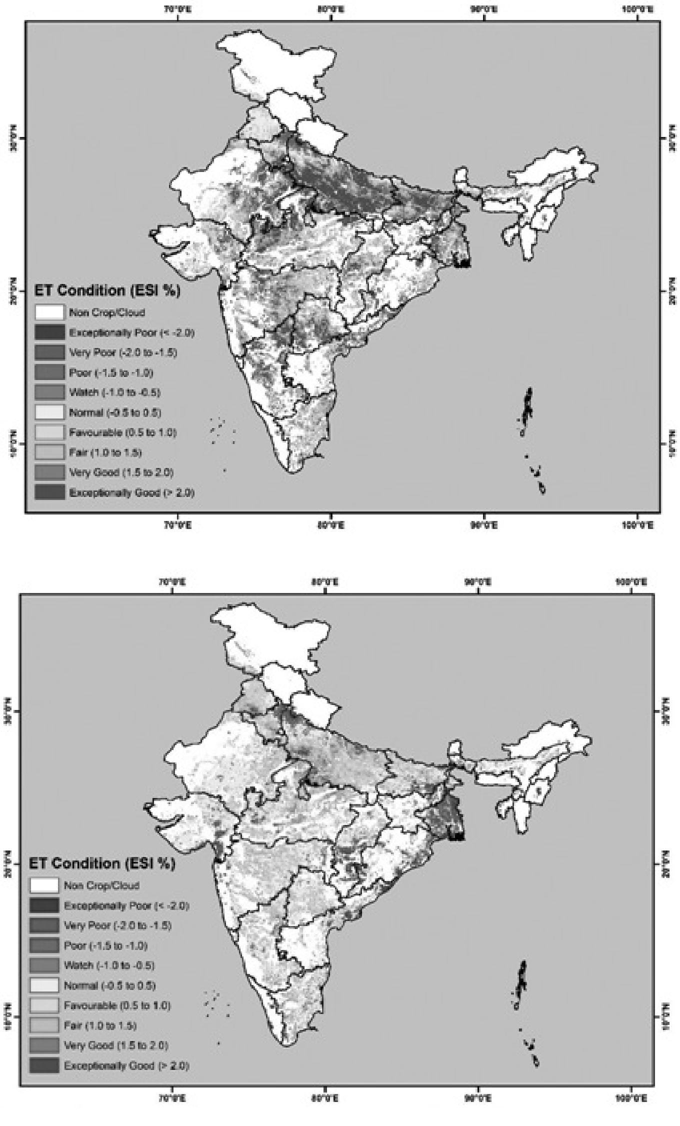

Figure1. Satellite-derived Evaporative Stress Index map between October 18 to November 18 in 2021 (a) and 2022 (b) year at 5X5 km resolution showing regions of drought-proneness areas. Negative values show below normal evapotranspiration rates, indicating vegetation stress due to lack of soil moisture [Source: Consortium for Research on Agroecosystem Monitoring and Modelling from Space (CREAMS), IARI, New Delhi]

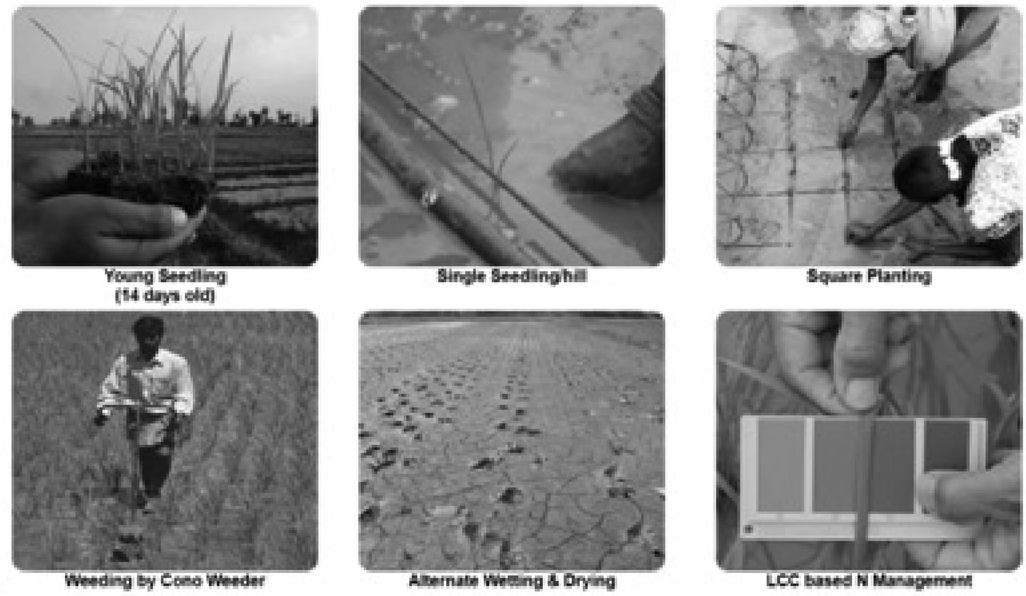

Figure 2. Major components of System of Rice Intensification [Source : TNAU web-portal; http://www.pustaka-deptan.go.id/rkb/knowledgeBank]

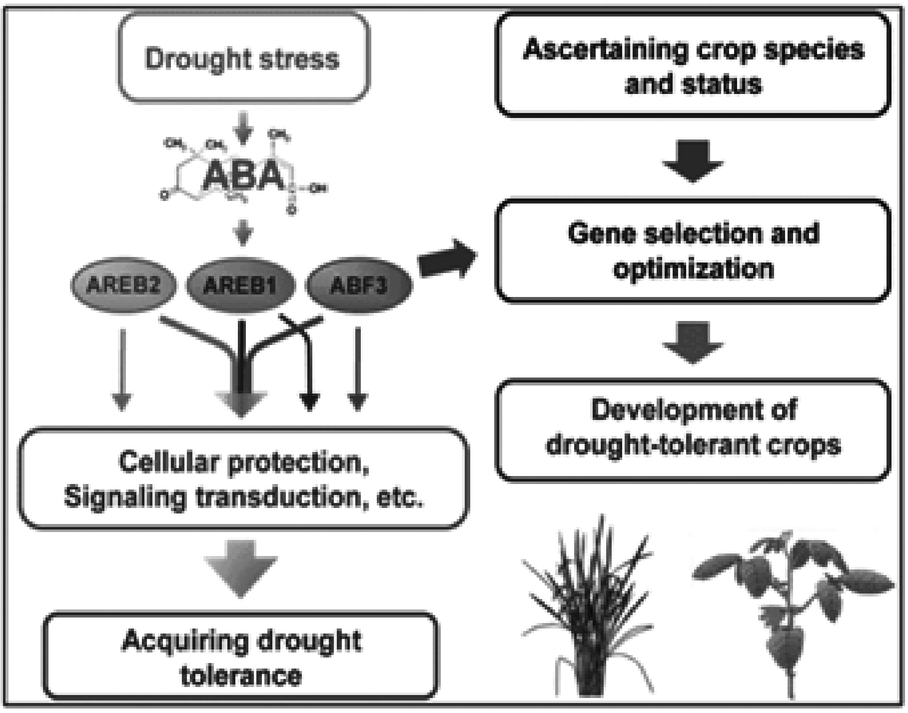

Figure 3. A general scheme on the development of abiotic stress-tolerant crops using three kinds of AREB-type transcription factors that cooperatively regulate ABA-mediated drought stress tolerance [Yoshida et al., 2010]

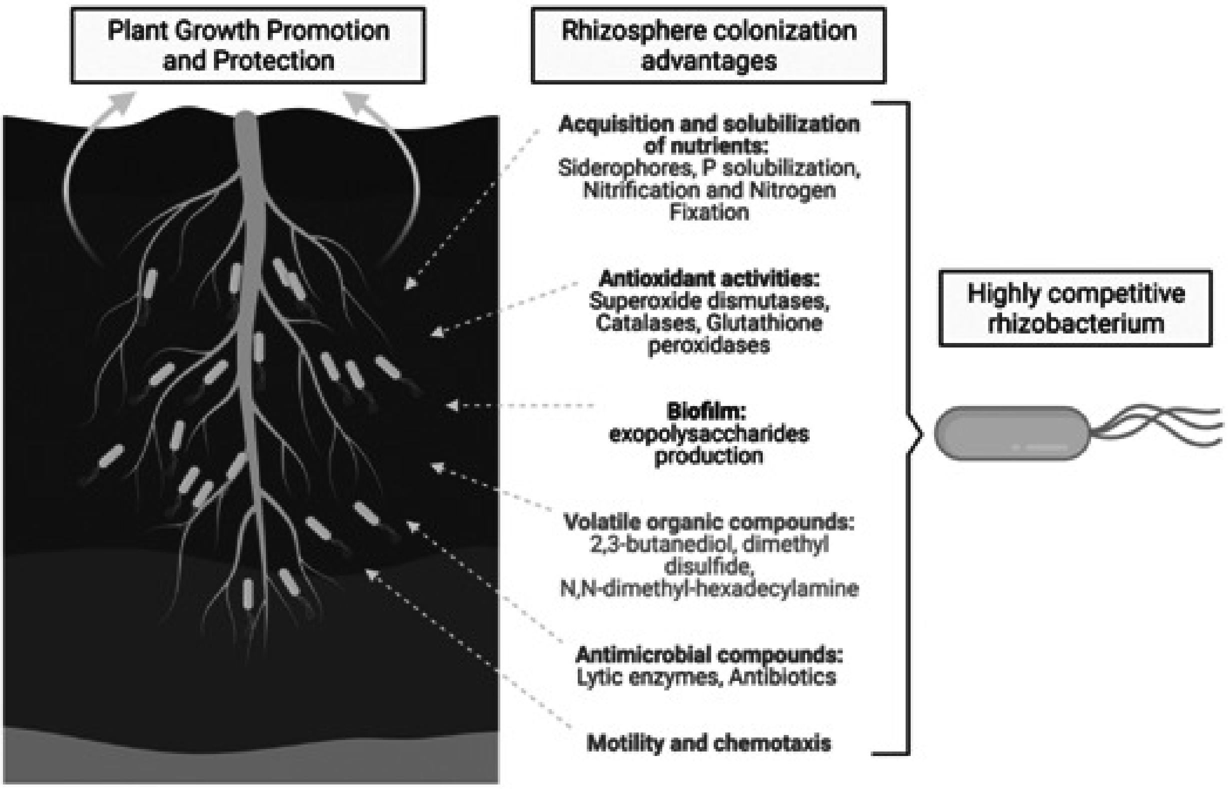

Figure 4. Mechanism used by Rhizobacteria to colonize the rhizosphere of host plants [Source : Santoyo *et al.,* 2021]

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