Annals of Arid Zone 54(3&4): 71-82, 2015

Physiological Aspects of Crop Productivity at Leh - Learning's from Hot Arid Region

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Abstract: Scientific laboratories and agricultural research stations in cold arid region of our country especially around Leh are still in infancy. Additionally, there are meagre reports on the understanding of different interventions that may have some potential to realize high agricultural yields in cold region. Therefore, initially we need to rely on results from hot arid regions. However, in order to enhance the probability of success, commonality between the two regions with emphasis on crop response at physiological plane, need to be thoroughly understood. This should be the basis of suggesting interventions that may be adopted as such or after fine tuning keeping in view the agricultural policy of the region and in consultation with the local farmers. Crop plants in the Indian cold arid region experiences both low temperature and water stress. Many agro-techniques related to genotype and fertility management along with use of growth regulators have been successfully adopted in hot arid region. The present article discusses some of these that may have relevance in cold arid region too. However, it is imperative to mention here that before suggesting blanket recommendations it shall be appropriate to arrive at a consensus decision after active participation of local farmers, agricultural scientists and policy makers so as to develop a holistic approach for the complete development of agriculture at Leh.

Key words: Arid, genotypes, fertility, management, plant physiology, low temperature, water stress.

The Arid Tract

India's arid zone is the most densely populated desert in the world. The area is about 59.2 Mha, which includes about 7.03 Mha of cold desert in Ladakh and Lahaul valleys. There are large tracts in north-western India and the interior peninsula that experience hot arid conditions also. Our area of interest in the present article i.e. the Indian arid zone is depicted in Fig. 1.

Aridity is a term that most people conceptually understand, and it evokes images of dry, desert lands with sparse natural surface-water bodies and rainfall, and commonly only scant vegetation, which is adapted to scarcity of water. Aridity has a wide variety of landscape manifestations including barren rock hills and plains, sand dune fields. It also occurs in regions with cold climates in which precipitation falls mainly as snow.

Soils at high altitude cold desert are coarse textured, permeable, deserted, and having poor water and nutrient holding capacity. Also, soil micro flora population is sparse due to poor soil structure, texture, very high sand and clay, low biological activity and freezing during long winter period in this region (Charan *et al.*, 2013).

A commonality can be drawn between the cold and hot arid region as depicted in Table 1 that lists important climatic and edaphic factors known to influence land productivity.

Issues at Leh

At Leh the situation of water scarcity is further aggravated by, degradation and overexploitation of valuable groundwater

Table 1. Weather and soil characteristics of Leh and Jodhpur

Parameters	Leh	Jodhpur
T min	-15.21 to 12.34°C	2.82°C
Tmax	-3.95 to 27.31°C	48.9°C
Av Rainfall	90 mm	360mm
Clay (%)	10.96-12.53	7.1
Sand (%)	52.4-69.99	87.2
Silt (%)	19.04-35.08	5.6
BD (g/cm^3)	1.38-1.44	1.51
pH	8.21-8.44	8.1
Texture	Sandy loam	Sandy loam
Reference	Charan *et al.*, 2013	CAZRI pub.

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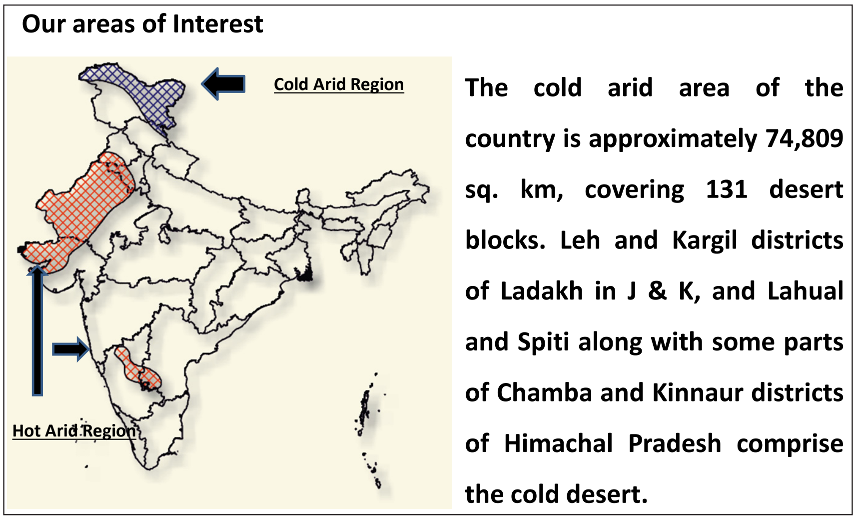

Fig. 1. Map showing demarcation of cold and hot arid regions of India.

resource due to unregulated rampant bore well development that need to be replaced by a well-managed plan (Dolma *et al.*, 2015).

In both Leh and Kargil districts, micronutrient status (zinc, iron, copper and manganese) are found to be below critical level and majority of soil samples have shown deficiency in its content (Acharya *et al.*, 2011). People freely graze livestock on highland pasture land but, given the very low moisture-holding capacity of the soil, the grazing productivity has been decreasing. This can be offset by strategies that require concentrated efforts on soil security wherein soil condition is optimally managed according to the inherent capability in at least 50% of managed soil systems.Toward achieving this goal, more specific objectives may include the following:

- Reduce soil nutrient depletion
- Increase water capture
- Increase carbon content of agriculture topsoil
- Reduce soil losses to the tolerable soil erosion rate

In cold arid desert freezing or extremely low temperature constitutes a key factor influencing plant growth, development and crop productivity. Response to low temperature is a highly complex process that involves an array of physiological and biochemical modifications. As evident from Table 1. Leh receives very less precipitation. Water for agricultural productivity primarily comes melting snow. Consequently most of the agricultural activity in the field is in summer months, at this time plants are exposed to chilling while in winters the temperatures are freezing.

Low temperature reactions and issues in cold and hot arid region

Chilling stress results from temperatures cool enough to produce injury without forming ice crystals in plant tissues, whereas freezing stress results in ice formation within plant tissues. Plants differ in their tolerance to chilling (0-15°C) and freezing (<0°C) temperatures. Both chilling and freezing stresses are together termed low temperature or cold stress. Low temperature may affect several aspects of crop growth; viz., survival, cell division, photosynthesis, water transport, growth, and finally crop yield. Before freezing at low temperature following aspects play key role either individually or collectively-

- Root resistance to water uptake increases due to increase in viscosity of water
- Root membrane permeability decreases
- Reduction in stomatal pore size
- Reduction in transpiration
- Water transport severely reduced/interrupted

All the above issues are manifested in terms of poor plant growth and productivity. Further, the cellular changes induced by either high or low temperature may lead to the excess accumulation of toxic compounds, especially reactive oxygen species (ROS) resulting

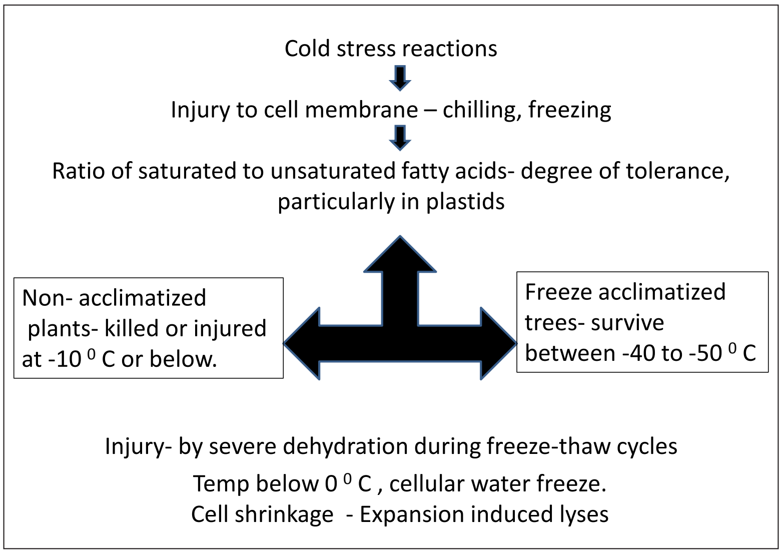

Fig. 2. Flow chart depicting a typical cold stress reaction.

in oxidative stress. ROS is also reported to accumulate under moisture and high temperature (Sharma *et al*., 2012), a situation commonly experienced by plants in the hot arid regions of the country. Chilling-sensitive plants exposed to low temperature usually show water-stress symptoms due to decreased root hydraulic conductance and leaf water and turgor potentials besides other typical cold stress reaction depicted in the Fig. 2.

Minor chilling stress at non-lethal temperatures is normally reversible. Such a recovery from adverse effects of drought upon rewatering at whole plant level and at metabolic plane have also been reported in case of hot arid region (Garg and Burman, 2002). Exposure to gradually decreasing temperatures above the critical range can also result in hardening of plants that may reduce or eliminate injury during subsequent exposure to low temperatures (Beck *et al*., 2004). Hardening effects upon exposure to sub-lethal water stress (i.e. when the tissue moisture is higher than permanent wilting percentage) has been reported in crops grown in hot arid region too. To avoid chilling injury, planting dates can be appropriately chosen as reported for rice genotypes (Farrell *et al*., 2006) though this is often difficult because of its effect on the later development of the plant. Adjustment of planting date and selection of suitable crop based on rainfall pattern and ambient temperature regimes is a common strategy of contingency crop planning done to realize high yield potentials in hot arid crops (Joshi and Kar, 2009). Cultivars bred for early vigor and maturity also helps in overcoming this problem. Other survival strategies relevant to cold arid regions that are known to yield convincing results are related to anti-freeze proteins (AFP) that

- Declines rate of ice crystal growth
- Lowers the efficiency of ice nucleation sites
- Lowers temperature at which ice forms

Besides this osmoprotectants/osmolytes like quarternary amines, amino acids, sugar alcohols (glycine betaine, proline, sugar alcohols –mannitol, trehalose- non reducing disaccharide) helps in water retention and desiccation tolerance. Osmoprotectants such as proline are also reported to play significant role in maintaining osmotic equilibrium between the symplast and apoplast and thus help in resisting low temperature damage by maintaining the functional integrity of the cellular membranes (Dionne *et al*., 2001). As in case of water stress in hot arid region (Garg and Burman, 2011), relationship between freezing tolerance and soluble carbohydrates, proline and water content in grapevines (Ershadi *et al*., 2016) clearly brings out the similarity in plant response to the two type of stresses. Further, Lyons (1973) highlighted phase transition of the lipid portion of the cellular membranes as the primary response to chilling temperatures. In hot arid region, water stress has also been reported to generate reactive oxygen species

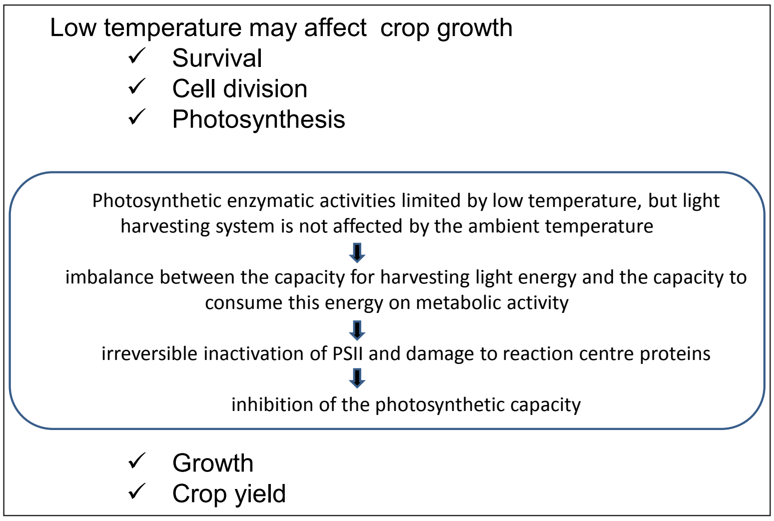

Fig. 3. Key issues related to crop growth and productivity at low temperature with emphasis on photosynthesis.

that in turn affects lipid peroxidation and consequently cause ion leakage. Measures of solute leakage or ion permeability have provided evidence of increased membrane permeability in response to chilling also. The plasma membrane is often considered the primary site of stress injury and electrolyte leakage. Increased membrane permeability could lead to an altered ion balance and also to the ion leakage observed from tissues under both chilling and water stress. Phase transition could also result in conformational changes in membrane bound enzymes and account for the observed discontinuities in the function of many enzyme systems. This may cause an imbalance between membrane bound and non-membrane bound systems. Over time the cells inability to cope with increased concentrations of metabolites could result in injury. Different tolerances to these metabolites could explain why some cultivars are more resistant to damage while still undergoing phase transition. Imbalances in metabolism, accumulation of toxic compounds, and increased permeability could all be the result of stress -induced phase transition (Mitter, 2006; Hasanuzzaman *et al.*, 2013).

Cell membrane plays major roles in water and nutrient movements within and outside the cell. Intra- and extracellular water and nutrient movement are inhibited due to low temperature as a consequence of membrane damage. There can be of two types of abnormalities, one that makes the membrane permeable to undesired nutrients and ions and causes ion leakage; another is cell membrane and cell wall can be ruptured by the cold which is also responsible for disrupting cellular homeostasis by destroying both intra and extracellular nutrient and water movements. Severe dehydration may also occur due to freezing of cell constituents, solutes and water. Available literature states that when temperatures drop below 0°C, the ice formation generally begins in the intracellular spaces because the intracellular fluid has a higher freezing point as compared to the other suborganalles of cell. Low and freezing temperatures also lead to cellular dehydration, reduce water and nutrient uptake and conduction by the roots in some plants, thus causing osmotic stress. Dehydration during cold occurs may be mainly due to reduction in water uptake by roots and a hindrance to closure of stomata.

The key issues likely to influence crop growth and productivity at low temperature of Leh are depicted in Fig. 3.

Low temperature affects several aspects of plant adaptation, e.g., freezing tolerance, plant growth, abiotic resistance and senescence. Among phytohormones, ABA, auxin, gibberellic acid (GA), thiols, salicylic acid (SA) and ethylene are related to the cold responses positively or negatively (Wang and Li, 2006; Yordanova and Popova, 2007). Reports of positive response of thiourea (Garg *et al.*, 2006), thiol derivatives (Nathawat *et al.*, 2016) and salicylic acid (CAZRI Annual Report 2014, 2015) under water deficit conditions also reflects similarity in response to the two types of stresses.

Looking for plants reflecting any of these mechanisms ……

STRESS ESCAPE

Ability of plants to complete its life cycle before serious soil and plant water deficits develop.

- ✓ Rapid phenological development
- ✓ Developmental plasticity

STRESS AVOIDANCE

Ability of plants to maintain relatively higher tissue water potential despite a shortage of soil moisture.

STRESS TOLERANCE

Capacity of plants to withstand water deficit with low tissue water potentials (To maintain integrity of cell membranes and prevent denaturation of proteins).

Fig. 4. Mechanisms for sustenance under stress.

Influence of environmental stresses depends on the frequency, intensity, type and duration besides the vulnerability and resilience of the species exposed to the stress factor. There exists specific stress tolerance or sensitivity to different stresses which requires specific ameliorative actions. Generalization at these steps may not work. Therefore, there is need to clearly understand that in years to come sustenance and growth in a fragile ecosystem as ours (both Leh Ladhakh and NW Rajasthan) shall depend on scientific basis of the stress impacts, alleviation mechanisms and subsequent development of do-able technologies for the region.

In both these regions (cold and hot arid), the water content and the water potential of plant tissues are the most important. Once a drop in water potential develops, responses of a wide range of physiological processes are induced, either directly or by plant hormones signaling changes in water status. Physiological traits relevant for the responses to water deficits and/or modified by water stress span a wide range of vital processes. As a consequence, it can be expected that there is no single response pattern that is highly correlated with yield under all water scarce environments. Furthermore, different crop developmental stages show different sensitivity to water stress that has also been found to be the case in arid legumes (Garg *et al.*, 2005).

Though India is considered rich in terms of annual rainfall and total water resources, its uneven geographical distribution causes severe regional and temporal water shortages. Under changing climate, shift in hydrological cycle is predicted and this is likely to influence rain (and also snow) –fed agriculture. Under these situations we need to look for plants exhibiting either of the mechanism as listed in Fig. 4.

In future, the significance of arid lands in national food security will further increase due to growing population pressure and competition for land for non-agricultural uses. These areas will have to shoulder more burden of providing food and feed in our country. Further, pockets in these lands may be marginal for agriculture but vital for grazing and biodiversity conservation. The knowledge already exists to significantly increase yields in rain-fed agriculture, even where water poses a particular challenge and large water investments focusing on water management are lacking. Farmers of these regions cannot afford large initial investments. Water resources need to be governed for long-term risk reduction through closer association among the relevant departments on issues related to legal, policy and management aspects (Sharma, 2011).

Adaptations

In the past, farmers have coped with erratic climatic conditions by adjusting their cultivation practices such as early planting and replanting when crop establishment was poor. The projected increase in climate variability, however, brings new risks that will require new adaptation options. Crop varieties grown today may not produce sufficient yields in the

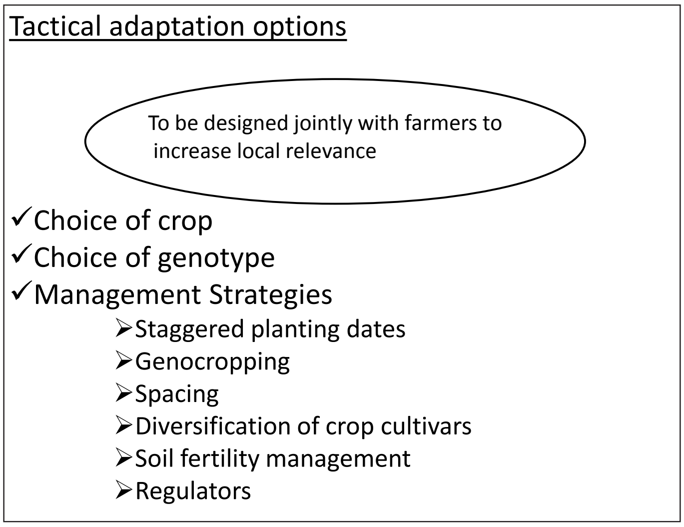

Fig. 5. Adaptation options for realizing yield under stress.

changed climate of tomorrow; better adapted, more stress-tolerant varieties, and new crops and cropping patterns need to be identified. This should be a continuous process so as to prepare ourselves to combat climate induced changes that are likely to influence agricultural productivity in cold and hot arid regions more.

Such adaptation options need to be designed jointly with farmers to increase local relevance. Adaptation can focus on shorter-term operational decisions (e.g. specific timing or sequencing of farm-ing activities), on medium-term tactical options (e.g. changes in crop rotations, or allocation of crops across fields), or on longer-term strategic decisions (e.g. to change the major crops grown, or adopt completely new activities. Some of the relevant options for these areas are listed above (Fig. 5).

Staggered planting dates on the same farm, manages risk of moisture stress at different times of the cropping season. In areas of recurring water shortage, one of the best strategies for alleviating water stress is the choice of crop and varietal manipulation, through which water stress can be avoided or its effects can be minimized by adopting varieties of short duration crops that either escape drought or are tolerant. If the water stress occurs during the middle of a growing season, corrective measures can be adopted which vary from reducing plant population to weed management. Diversification of crop cultivars is also a potential option for adaptation (IPCC, 2007). Continuous cropping without sufficient inputs puts extra pressure in addition to the existing problem. Therefore, integrated soil fertility management (ISFM) is a potential entry point for adaptation. The positive response of important kharif crops to applied fertilizer (mainly N and P_2O_5) is well known (Narain *et al.*, 2000). However, it has been found to vary with soil type, seasonal rainfall during the growing season and growth stage of the crops. As nutrient and water requirements are intimately linked and fertilizer application increases water use efficiency, therefore, the interaction between soil moisture deficits and nutrient uptake is of paramount importance and a subject of extensive studies. A good rainfall event can be fruitfully harvested by collecting rain in farm ponds or tanks than can be recycled as life saving irrigation during a prolonged dry spell.

In fact, all such strategies related to water conservation need to fine tuned for Leh considering our experiences in hot arid region

Table 2. Comparative performance of arid legumes exposed to water stress at vegetative and flowering stage at Jodhpur (Source: Garg et al., 2005)

Legumes	Seed yield (g plant^{-1})		
	Control	Drought at vegetative stage	Drought at flowering stage
Clusterbean	7.60	6.97 (8.3)	5.10 (26.8)
Moth bean	4.13	4.03 (2.4)	3.17 (23.2)
Cowpea	10.03	8.71 (13.2)	5.35 (46.7)
Mung bean	7.64	5.72 (25.1)	4.55 (40.4)

Per cent reduction over control within parenthesis.

at north west Rajasthan as they are location, time, crop and socio-economic conditions specific.

Genotypic variations and agronomic practices

Better crop management including appropriate selection of crops, their genotypes, planting dates, row spacing and plant populations may greatly help in alleviation of drought effects (Kathju *et al.*, 2003). Genotypic variation in the ability of pearl millet, a principal hot arid zone crop, to withstand water stress is well known since early sixties. Variation in adaptation of pearl millet cultivars to arid conditions was also indicated by relatively higher yields of land races than those of hybrids (Kathju *et al.*, 2001). Arid legumes also differ in their response to drought (Table 2) and this helps in crop contingency planning in the event of drought. In this context, there is need to develop such a contingency planning considering the local crop (and fodder) needs under water scarce, low temperature and low soil depth conditions of Leh also.

In past several attempts have been made to minimize the detrimental effects of drought in arid zone crops. Both seed size and genotypes significantly influenced early vigour, number of tillers per plant, plant height, days to wilting initiation, days to permanent wilting and dry matter production. Pearl millet plants from larger seeds took longer to initiate wilting and then permanent wilting compared with plants from smaller seeds. Further, a moderate population of 88,888 plants ha^{-1} (equal proportion of pearl millet and clusterbean) was optimum for row intercropping (1:1) and strip cropping (4:4) in the moisture sufficient season, and low (40 000 plants ha^{-1}) to moderate populations produced satisfactory yields in the moisture stressed season.

For stability of yield under conditions of fluctuating water availability and extreme temperature regimes, planting of early and late genotypes may be most appropriate under both hot and cold arid region. Geno-cropping in both mothbean (Kathju *et al.*, 2003) and clusterbean (Vyas *et al.*, 2003), particularly under low moisture situation could be attributed to more efficient use of water, low initial canopy development and higher photosynthetic rates (Table 3).

Fertility

Our investigations on arid zone crops have established significant positive response of plants to improved soil fertility, particularly N and P. However, the degree of yield response varied with rainfall pattern, intensity of drought, native soil fertility and crops species. On the basis of various experimental data obtained on sandy soils, it has been found that advantages of fertilizer application under arid conditions may be realized in situations in which dry and wet phase exist during the growing period. However, the benefits of nutrients under such drought conditions are likely to be less than in well irrigated crops.

Studies suggested that tissue hydrature was not an infallible index of metabolic efficiency as nutritional status of plants was often more critical under water deficits for enhanced leaf metabolism, photosynthesis, growth and yield. "Arid areas are not only thirsty but hungry

Table 3. Comparative performance of moth bean and clusterbean genotypes under bad (266 mm) and good (424 mm) rainfall situations at Jodhpur (Source: Kathju et al., 2003; Vyas et al., 2003)

Planting pattern	Seed yield (kg ha^{-1})		WUE (kg ha^{-1} mm^{-1})		Net Photosynthesis (m mol m^{-2} s^{-1})	
	266 mm	424mm	266 mm	424mm	266 mm	424 mm
Moth bean						
Early (RMO-40)	744	825	2.66	2.29	11.3	19.2
Late (Maru moth)	528	1011	1.88	2.80	9.7	20.5
E + L	755	1188	2.72	3.32	12.3	22.0
Clusterbean						
Early (Suvidha)	833	986	2.89	2.66	22.7	26.8
Late (Maru guar)	717	1122	2.54	2.93	21.0	26.0
E + L	928	1172	3.20	3.16	23.6	27.8

too" is a well proven connotation (Garg and Burman, 2011). Low fertility level of these soils is attributed to low organic matter status a result of slow biomass decomposition and erosion and immobilization of nutrients

The adverse effect of water stress, no matter at which stage of growth the water shortage was experienced, may be substantially evaded where optimum plant vigour was induced by adequate level of soil fertility. Adequate nutrition conducive for greater plant vigour brings about an efficient enzyme activity and higher chlorophyll content, despite desiccation, as compared to plants raised under low soil fertility

High soil fertility under low moisture conditions seems to favorably influence the yields of arid legumes also. Alleviation of drought effects in arid legumes has also been achieved through P application which favorably modulates various physiological and biochemical processes (Table 4).

Furthermore, in late moth bean genotypes where impact of drought was more severe P application (40 kg ha^{-1}) significantly ameliorated the detrimental effects of water stress on plant water potential, relative water content, rate of net photosynthesis, levels of total chlorophyll, starch, soluble protein and nitrate reductase activity. In clusterbean also results indicate the possibility of alleviation of water stress effects by P nutrition at least up to moderate stress level. Recovery upon re-watering was also more in P-fertilized than unfertilized plants.

Experiments related to management of nutrient availability through tillage operations and residue incorporation under varying rainfall situations revealed that application of pearl millet, clusterbean and moth bean residues @1.5-2.0 t ha^{-1} increased moisture storage and also resulted in high pearl millet yields. Further it has been established that the most promising route to improving inorganic fertilizer efficiency in cropping systems is by adding small amounts of high-quality organic matter (possessing a narrow C/N ratio and a low percentage of lignin) to soils (Aggarwal *et al.*, 1996). This provides readily available N, energy (carbon), and nutrients to the soil ecosystem, and improves structure, and increase soil microbial activity and nutrient cycling and reduces nutrient loss from leaching and denitrification. Such fertility management strategies need to be developed considering the local flora and cropping systems of Leh. Further, concepts like synchronization of fertilizer application with plant growth and use of slow releasing organic matrix based fertilizers that have immense potential in realizing high yields in arid region need to be fine tuned under conditions at Leh. The latter encompasses a technique wherein agro-waste materials similar (but not limited) to cow dung, clay soil, neem leaves and rice bran are used as organic matrix for the immobilization of chemical fertilizer nutrients with commercial grade binders so as to facilitate availability N for longer duration due to either nitrification inhibition and/or stabilization of the degradation of organic nitrogen forms.

Numerous experiments have indicated a high pay-off from applied nutrients in arid lands but the responses to applied fertilizer have been found to vary with the soil type, available water storage at sowing, seasonal rainfall during the growing season and the crop species. Application of fertilizer in nutrient-deficient arid soils increases the crop growth, yield and WUE. Physiological mechanism of drought-fertility interaction has been thoroughly

Table 4. Effect of moth bean genotypes to phosphorus nutrition at Jodhpur (Source: Garg et al., 2004)

Parameters	Stress	P levels (kg ha $^{-1}$)	Percent increase by P	Parameters
		P_0	P_{40}	
Chlorophyll (mg g^{-1} dw)	C	8.25	8.83	7.0
	D	7.16	7.90	10.3
Photosynthetic rate (µmol m^{-2} s^{-1})	C	9.67	11.42	18.1
	D	5.44	6.80	25.0
Seed yield (g plant^{-1})	C	2.57	2.90	12.8
	D	1.53	1.96	28.0

Data mean of four genotypes (RMO-257, CZM-18, Jawala and CAZRI Moth-1).

explored in pearl millet, sesame, clusterbean, moth bean and Indian mustard. It has been concluded that fertility induced metabolic efficiency coupled with higher photosynthetic rate and nitrate reductase activity as well as nitrogen assimilating enzymes, for efficient N utilization are the key mechanisms leading to enhanced growth and yield (Burman and Praveen-Kumar, 2014).

Besides N and P, deficiencies of micro-nutrients especially Zn and Fe have also been reported (CAZRI Annual Report, 2010). Major reason of the increasing nutrient deficiency is higher nutrient removal by crops than that added in soil either naturally or through anthropogenic sources. Rainfed soils are no exception and a negative nutrient balance (1.81 to 14.03 kg ha^{-1} for N, 0.55 to 3.20 kg ha^{-1} for P and 8.60 to 45.62 kg ha^{-1} for K) has been reported for aridisols (Narain and Praveen-Kumar, 2003). According to an estimate by 2025 for feeding a projected population of 1.4 billion, it shall be necessary to use 30–35 Mt of NPK from fertilizers and 10 Mt from organic and biofertilizer sources. This coupled with the fact that the current gap between nutrient removal and application is 10 Mt and 50% of applied N escapes either as gaseous emission or nitrate leaching, there shall be urgent need to identify viable botanicals preferably from local flora which can also act as nitrification inhibitors. Additionally, other approaches such as optimization and internal circulation of nutrients as discussed below has potential in cold arid region also.

Application of optimum quantity: As water availability and nutrient mobility are closely interlinked, aridity limits the rate and amount of nutrient movement. Thus, uncertainties in soil nitrogen (N) supply in rainfed agriculture and crop N demand present a challenge to scientists in deciding on N fertilizer rates. Most extension services in India provide a single, standard fertilizer recommendation for an entire district or region. Farmers apparently have few guidelines for adjusting N-fertilizer amount to account for the large differences in the indigenous N supply, indicating the need for a 'field-specific' approach to N management. Field-specific N management could lead to substantial reductions of N rates without yield loss in a wide range of cropping systems, thereby improving profitability and environmental quality.

Internal nutrient circulation: The practice of effective use of inorganic and organic sources of nutrients in a proper proportion not only reduces the requirement of inorganic fertilizers but it also improves physical conditions of soil, enhances water retention capacity and its availability in the soil. In arid rainfed areas, cereal stover is often fed to livestock, and manure is applied in field. This way of recycling the residues is more beneficial for crop than their direct application in field. Losses of N from such systems are often high. Cattle manure is applied in a dried, aerobically decomposed form, often with a high sand content and an N content that is frequently around 1% or less.

Thus, to be successful in nutrient management for sustainable crop production 4R strategy emphasizing the need for right fertilizer source, right rate, right time and at the right place need to be practiced.

Additionally, weeds in crop also increase competition for both water and nutrients. They also markedly reduce light interception, increase ratio of red to infrared radiation, decrease transpiration rate and enhance soil temperature and specifically revealed poor microenvironment in arid zone. Thus weeding is an important cultural practice that mellows adverse effects of water scarcity (and interlinked nutrient competition) in both hot and cold arid region. Considering the agricultural policy of the Leh region that is for non-chemical means of agricultural production, there is need to educate the farmers regarding weed management preferably by mechanical mean or by crop rotation. Further, potential use of on farm wastes for composting and/or management of disease incidence on the lines similar to one advocated in hot arid region for controlloing *Macrophomina* and *Fusarium* infestation (Lodha and Burman, 2004) needs to be explored also. Needless to say the composted material shall also suplement the nutrient requirement to some extent.

Growth regulators

Plant growth and performance have been reported to be influenced by growth regulators. Few attempts of utilizing regulators for improving productivity have also been done on arid zone crops under soil moisture stress**.** Kinetin (5 ppm) applied as either pre-sowing

Table 5. Effect of phosphorus, nitrogen and thiourea on photosynthesis of clusterbean at Jodhpur

Treatments	Photosynthesis (μ mol m^{-2} s^{-1})
P (kg ha^{-1}) 0	17.60
20	19.18
40	20.80
N (kg ha^{-1}) 0	17.87
20	20.56
THIOUREA C	16.96
TH	21.85

Source: Burman *at al*., 2007.

seed treatment or foliar spray (at 25 and 40 DAS) or both significantly improved the growth, dry matter production and seed yield of field grown clusterbean under moisture deficit condition. Kinetin mediated response was due to higher content of different leaf metabolites (starch, soluble protein, etc.) thereby, prolonging the active growth phase (Burman *et al*., 2005). Application of senna stem (as such or as foliar spray of its aqueous extract) also promoted growth and increased yield of pearl millet primarily due to presence of nutrients and triacantanol (Garg *et al.,* 2007). There is need to identify similar plants that are native of Leh and also reflect potential to enhance growth and yield of barley, potato, alfa-alfa besides other cash crops currently promoted at Leh under protective agriculture.

Seed treatment with thiourea (500 ppm) followed by foliar sprays (1000 ppm) at vegetative and flowering stages significantly mitigated the detrimental effects of field water stress in clusterbean through enhancement of photosynthetic efficiency and nitrogen metabolism (Garg *et al.*, 2006). Positive interaction of fertility with thiourea has also been reported (Burman *et al.*, 2004, 2007) which have improved yields primarily through positive effects on photosynthesis (Table 5). Other plant processes are also positively influenced by application of thiourea (Fig. 6).

Conclusion

To conclude water scarcity by far leads to the most important environmental stress i.e water stress in both cold and hot arid region and many efforts have been made to improve crop productivity under water limiting conditions. While natural selection has favored mechanisms for adaptations and survival, breeding activity has directed selection towards increasing the economic yield of cultivated species. Meanwhile, fundamental research has provided significant gains in the understanding of the physiological and molecular responses of plants to water deficits but there is still a large gap between yield in optimal and stress conditions.

A number of physiological studies have identified some traits for which presence or

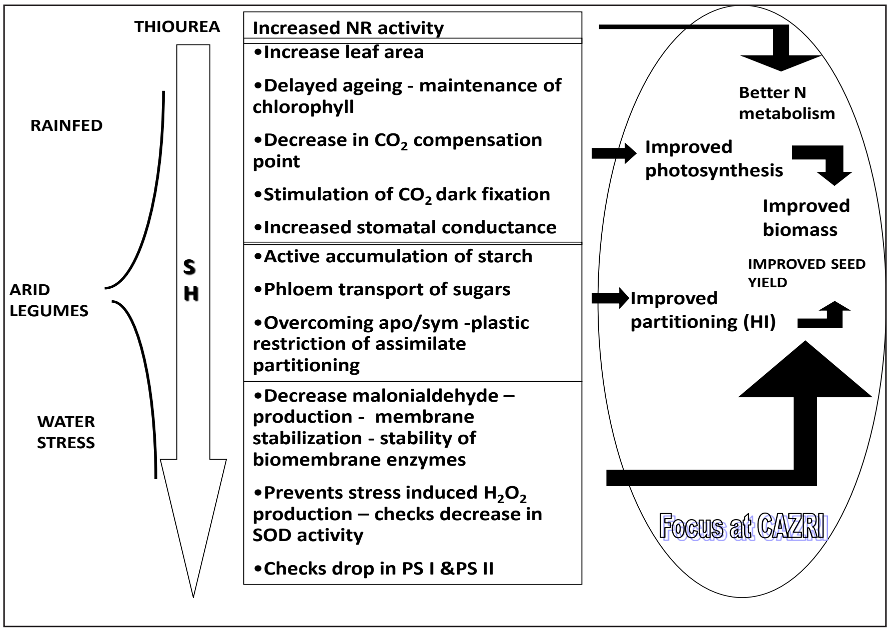

Fig. 6. Processes influenced by thiourea application.

expression is associated with plant adaptability to drought-prone environments. However, a critical aspect in all studies dedicated to water stress tolerance is the assessment of the degree of tolerance of different genotypes. In many studies the identification of tolerant and susceptible cultivars is based on few physiological measures related to drought response. It is worth mentioning here that such morpho-physiological traits should be constitutive (i.e. also expressed under optimum condition) and stress-responsive (i.e. expressed only under pronounced stress situations). In this respect, emphasis should be given to traits that constitutively enhanced yield *per se* and also enhanced plant survival under cold and/ or water stress conditions.

Discussion in the preceding paragraphs clearly brings out need for a holistic approach related to all aspects of agricultural productivity and for this eight core "national missions" running through 2017 form the backbone of natural resource management in our country.

- National Solar Mission
- National Mission for Enhanced Energy Efficiency
- National Mission on Sustainable Habitat
- National Water Mission
- National Mission for Sustaining the Himalayan Ecosystem (Addressing to Cold arid region also)
- National Mission for a "Green India"
- National Mission for Sustainable Agriculture
- National Mission on Strategic Knowledge for Climate Change

At the end, from the farming community point of view we should be able to address to the queries like -

i. Given a natural resource status (soil, ground water, precipitation and nutrients) which crop and /or which genotype is likely to be more remunerative on a sustainable basis?

ii. Having a genotype (or a pool) of a defined growth characteristics which intervention (irrigation and/or fertilization etc.) is likely to help in realizing yield potential of crops in cold or hot region?

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