The Pharma Innovation Journal 2021; 10(10): 2537-2542

www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2021; 10(10): 2537-2542

www.thepharmajournal.com
Received: 13-08-2021
Accepted: 15-09-2021

Transpiration suppressants and their role in climate change scenario in dryland agriculture

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Abstract
Rainfed agriculture, where crop production is exclusively dependent upon rainfall, covers about 80% of the world's cropland, contributes 60% of the cereal grains and generates livelihood in rural areas (Samara, 2002) [16]. About 43% of 97 m ha rainfed lands are dryland in India with less than 75 cm annual rainfall. "Drylands are not only thirsty but hungry too". The primary constraints to agricultural production in dryland areas are lack of suitable soil and water management technologies as a result of highly fragile ecosystems which further have been worsened presently due to the global climate change (NRAA, 2007) [8]. Hence, saving single droplet of water and maintaining sustained fertility levels is the great challenge in drylands. Use of transpirant suppressants and plant growth regulators would be one amongst the several alternatives in this regards (Ansary M. A. 2011) [2]. Transpiration accounts for a phenomenal loss of water from the crops as nearly 99% of the water absorbed by plants is lost through this mechanism (Prakash and Ramchandran, 2000) [17]. Transpiration can be retarded either by increasing resistance of stomata and boundary layer or by decreasing vapour pressure gradient. Materials applied to the transpiring plant surface with the aim of reducing water loss from the plants are called anti-transpirants and also known as "transpiration suppressants". Broadly, four types of transpiration suppressants, *viz*. reflective, stomata closing, film forming and growth retardant types are common to reduce the rate of transpiration in arid and semi-arid zones. Plant growth regulators are organic compounds occurring naturally in plant as well as synthetic, which in small amounts is effective to arrest excessive vegetative growth, flower and fruit shedding and control of flowering thereby resulting in increased crop yields. The transpiration suppressants treated plants exhibit higher relative water content, water potential and lower temperature of leaves than control (Ansary *et al*., 2005) [1]. Among the transpiration suppressants, Kaolin recorded the highest leaf albedo and gained popularity in dryland research (Rana *et al*., 2006) [14] Hence, transpiration suppressants could be used to optimize yield levels under uneven and irregular distribution of rainfall for better crop growth, yield and water use efficiency under dry land environment. However, further extensive research works on proper sources and concentrations, timings and frequencies of application of transpiration suppressants for different crops are really needed to make the dryland farming more productive on long-run.

Keywords: Dryland, transpiration suppressants, crop productivity, economics, water use efficiencies

Introduction
Rainfed agriculture, where crop production is exclusively dependent upon rainfall, covers about 80% of the world's crop land and produces not only most of the world's cereal grains (more than 60%) but also generates livelihood in rural areas (Samara, 2002, NRAA, 2007) [6, 8]. Out of 143 m ha of cultivated area in India, 67% is rainfed. Rainfed agriculture extends over 97 million hectares of which nearly 67 m ha falls in the mean annual precipitation range of 500-1000 mm (Khan and Narain, 2003, Khan *et al*., 2001) [6, 7] in India. About 91% area of coarse grains, 91% pulses, 80% oilseeds, 60% cotton, 50% rice and 19% wheat in India is produced solely from rainfed lands of which 43% share is through dryland (Prasad and Bhatia, 2009) [12]. The details of major crops area and production under rainfed agriculture in India have been shown in Fig 1.

Hence, rainfed areas will have to be the focus of India's future agriculture revival with a different paradigm of development and upgrading rainfed agriculture promises large social, economic and environmental paybacks, particularly in poverty reduction and economic development. The climates of drylands are characterized with arid or semi-arid types where there is less rainfall (< 75 cm) and higher potential evapotranspiration (PET). In dryland there is moisture induced drought at any stage of crop growth and hardly it is of 75-120 days growing periods (Tetarwal, J. P. and Rana, K. S., 2006) [18]. The primary constraints to agricultural productivity in dryland areas are the lack of suitable technologies for soil and water management because these are the highly fragile ecosystem and the global climate change has posed the acute problems in these areas more recently.

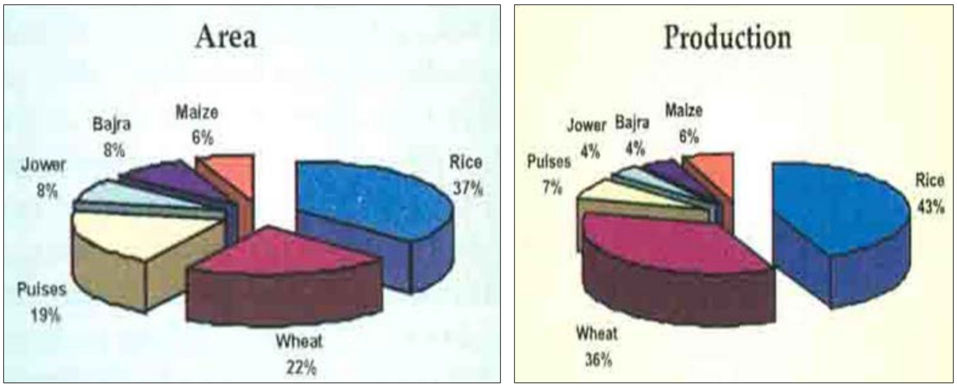

Fig 1: Relative area and production of food grains (%) in rainfed areas in India

Drylands are not only thirsty but hungry too. Hence, saving single droplet of water and maintaining fertility levels will be beneficial for which use of transpiration suppressants and growth regulators could be sustainable (Ghosh, D. C. 2009) [3]. India needs 325 mt of food grains for 1.5 billion populations by 2025 for which the annual progression of food grains growth would be 7.3 million tons/year. To meet the demand of cereals, legumes and oilseeds by 2030 over the 1994-96 bases, there is real need of 38-45%, 64-76% and 40-48% increment in production, respectively. Therefore, the rainfed/dryland area should be properly utilized to achieve the evergreen revolution in India. The average yield of course grains growing in rainfed lands is far below (0.88 t/ha) than the irrigated crops (2.0 t/ha) and same is the case with cotton, pulses and oilseeds (Singh *et al.,* 2000) [17]. Hence minimizing the huge yield gaps is the major concerns of agronomists at now.

Climate change and dryland agriculture

About more than dozen of problems like harsh environment and more incidence of disease, pest and weeds have been tackled by the resource poor farmers in dryland areas including with the scanty soil moisture and fertility levels. The increasing areas of decreased water table and the induced climatic variability created by anthropogenic factors especially after 1970's have created more serious issues in the dryland farming (Table 1 and 2, and Fig 2 and 3). The average temperature in India has been raised @ 0.22ºC per decade during the last 30-40 years in comparison to the last 150 years of the history. Drylands are more affected with this phenomenon because the farmers in drylands are resource poor and they cannot afford the resources to cope with the negative consequences of climate change (Pandey, S.K. 1983) [10]. The increasing years of drought in last 50 years over the 200 years of historical weather records justified that the real problems of rainfall are hitting the most parts of the country in general and dryland in specific (Table 2).

Table 1: Projected changes in temperature and rainfall in India upto 2080

Year/ Scenarios	Season	Temperature change (^{0}C)		Rainfall Change (%)	
		Lowest	Highest	Lowest	Highest
2020s	Annual	1.0	1.41	2.16	5.97
	Rabi	1.08	1.54	1.95	4.36
	Kharif	0.87	1.17	-1.81	5.10
2050s	Annual	2.23	2.87	5.36	9.34
	Rabi	2.54	3.18	-9.92	3.82
	Kharif	1.81	2.37	7.18	10.52
2080s	Annual	3.53	5.55	7.48	9.90
	Rabi	4.14	6.31	-24.83	-4.50
	Kharif	2.91	4.62	10.10	15.18

Source: Joshi and Kar (2009) [5]

Table 2: Number of drought years in India over the two century (1800-2000)

Period	Severe drought years	Total numbers of drought years
1801-50	-	9
1851-1900	1877, 1899	9
1901-50	1901, 05, 18, 41	12
1951-2000	1941, 65, 72, 79, 87	15
Total	11	45

Source: Jat *el al.* (2010) [4]

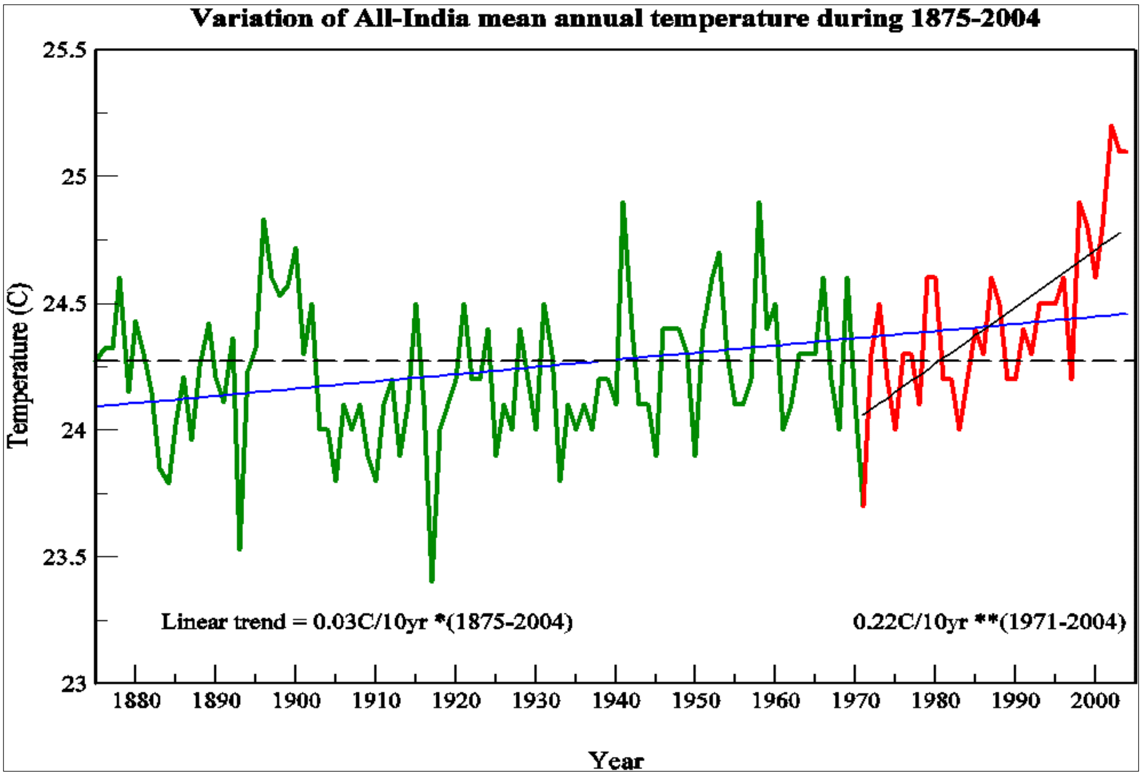

Fig 2: Variations of all India mean annual temperature during 1875-2004

The levels of ground water depletion are more in the last 10 years in the history of last 50 years (Fig 3). Recharging of ground water seems possible only with the proper harvesting of the rainfall that occurs in the dryland/ rainfed lands. This is the single alternative resource remained unexploited by the majority of poor farmers in dryland areas. Either minimizing transpiration or evaporation loss or combination of both evapotranspiration losses would give some saving in water expense and increase the water use efficiency in dryland farming. There is a critical need to balance water availability, water requirements and water consumption in conserving water which has become a decisive consideration for agricultural expansion, particularly in arid and semi-arid regions where water is the main limiting factor for plant growth. The use of anti-transpirant is one amongst the several important issues taken due care from the earlier time in India with the establishment of All India Co-ordinated Research Centre for Dryland Area (AICRCDA) in 1970 and ICRISAT in 1972. The establishment of 23 dryland/rainfed research stations throughout the country has made several efforts on this line.

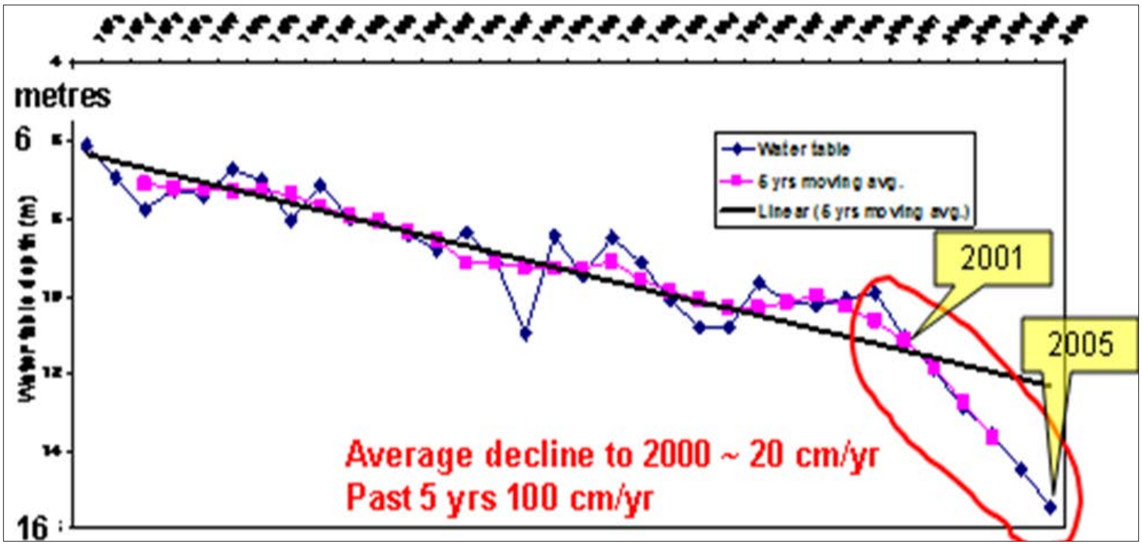

Fig 3: Variations of ground water levels in the soil profile of North West India (1875-2004)

Transpiration and their mechanisms

An actively growing plant transpires a weight of water equal to their leaf fresh weight each hour under conditions of arid and semi-arid regions if water is supplied adequately, but this conditions seldomly exists in the field (Table 3). This scare figure makes it necessary to find ways by which available water could be economically utilized.

Table 3: Crop water requirements and transpiration rate for some major crops of dryland areas

Dryland crops	Water requirement	Transpiration rate (Liters/ day/plant)
Cereal + Legumes	400-500 litres/kg grain	-
Fruits +vegetables	1000 liters/kg output	-
Maize	Maize plant water use	200
Sunhemp	Cell constituent- 1,872 g	27
Cotton	Metabolic use- 250 g	8-10
Citrus	Transpiration- 20.21 kg	100-200
Trees (10 m ht)	Total growing season–	300-800
Forest trees (400-600 trees)	20.43 kg	20000 barrels/ day

Source: Pandey and Sinha (2009) [9]

The soils of dryland are mostly deficit of moisture and feels drought at any growth stages of the crop. The transpiration cannot be controlled totally because it is a physiological process of a plant to maintain the plant alive and for its proper functioning. However, it could be minimized when the rate of crop coefficient value is higher to minimize the transpiration loss from the plant body (Punuri, R. 1979) [13]. The end of leaf growth or maximum vegetative and ear emergence period is the time of maximum transpiration loss in the dryland crops and the use of transpiration suppressants are suggested to use at this time interval (Table 4).

Table 4: Phase-wise variations in pearl millet crop coffcient values in dryland areas

Growth stages	100% potential evapo-transpiration conditions
Emergence- Juvenile phase	0.34 - 47
Tillering	0.66 - 1.10
End of leaf growth	1.12 - 1.35
Ear emergence/ Anthesis	0.76 - 0.97
Maturity	0.60 -0.76
Entire season (average)	0.772

Source: Rao and Singh (2007) [15]

The crops grown in drylands are mostly in the condition of moisture and nutrient stress and their yields are not stable because of less water use efficiency and shortest crop growth periods in comparison to the irrigated and well distributed rainfall years (Singh, T. and Rana, K. S. 2006) [19]. Hence, suitable technological interventions are needed to increase the water use efficiency so that dryland crops can take more thermal unit to maturity and thereby increase the yield (Table 5).

Table 5: Mean water and heat use efficiency (HUE) of pearlmillet cv HHB 67

Treatment	Seasonal ET (mm)	Yield (kg/ha)	WUE (kg/ha-mm)	GDD (^{0}C Day)	HUE (kg/ha/^{0}C/day)
Control	224.0	855 ± 25.3	3.82	1252	0.68
50% PET	291.0	1504 ± 40.8	5.17	1310	1.14
100% PET	362.0	2049 ± 57.3	5.66	1364	1.50

Source: Rao and Singh (2007) [15]

Factors affecting transpiration

Waggoner (1966) [20] has represented transpiration processes as follows:

$$T = H_2O / r_s + r_a$$

Where, T = rate of transpiration
H_2O = the difference of water potential or vapour concentration between mesophyll cells and free air outside
r_s= stomatal resistance, and
r_a= boundary layer resistance.

This indicates that transpiration can be retarded either by increasing resistance of stomata and boundary layer or by decreasing vapour pressure gradient. Certain chemicals with some biological activities could be used to reduce the transpiration rate and mitigate plant water stress by increasing leaf resistance to diffusion of water vapor. Hence, transpiration is an energy dependent process dependent on solar radiation. Plant leaves utilize only a part of solar radiation which is falling on their surfaces and most of this is consumed in warming the leaves. Transpiration accounts for a phenomenal loss of water from the crops as nearly 99% of the water absorbed by plants is lost through this mechanism (Prakash and Ramchandran, 2000) [17].

Transpiration suppressants, classification and role in dryland farming

A transpiration suppressant is any material applied to the transpiring plant surface with the aim of reducing water loss from the plant and it is synonymously called anti-transpirant. Any organic compounds occurring naturally in plant as well as synthetic which in small amounts promote, inhibit or modify any physiological process in plants is called plant growth regulators. There are four types of anti-transpirant that generally exist in use in dryland farming to suppress the evapotranspiration.

(a) Reflective type

The reflective type of anti-transpirants is suspension types of material which after spraying on the foliage, form a monolayer coating. This coating increases the albedo and decreased the net radiation load and temperature as a result the vapour pressure gradient and finally transpiration is reduced. Light saturation occurs at about 2000 c. ft. while during mid-summer illumination generally remained 6 to 8 times higher than this level. Thus, by reflecting back a portion of the light, transpiration can be reduced without a possible decrease in photosynthesis. White materials like Kaolinite, Lime, Hydrated lime, Zinc sulphate Magnesium carbonate etc. could be used as light reflecting materials. These are locally available and are cheap in price.

(b) Stomata closing type

These compounds induce stomata closing and referred as stomata closing materials. The theoretical basis for closing stomata as a means of reducing transpiration is the alternation in the permeability of the guard cell membranes, thereby making more permeable to solutes. Some chemicals would affect the metabolic reactions responsible for decreasing the turgor pressure of guard cells. This effects the energy system required for active uptake of solutes particularly K salts. Some chemicals might reduce photosynthesis causing buildup of carbon dioxide at intercellular spaces which results in stomatal closure. Most of the chemicals of this group have been either toxic or slow down plant growth and sometime also brings about undesirable side effect. The various chemical could be used like Phenyl mercuric acetate, (PMA), Atrazine, Abscissic acid, Alachlor, Chlormequat (CCC), Sodium azide, L-hydroxy sulphonate, Alkanyl succinic acid, Hydrogen fluoride daminoide etc. when sprayed in low concentrations act as anti-transpirant.

(c) Film forming type
The materials which when sprayed on the foliage to form a thin film for creating resistance in the path of water vapour diffusion from leaf to atmosphere are film forming types. The chemical like Silicons, Polyethylenes, Wax, Latex and Fatty alcohols etc. are the some of the important chemicals of this group.

(d) Growth retardant type
The chemical like Cycocel (CCC), Uniconazole and Mepiquat chloride reduce shoot growth which increase root growth. The reduced shoot growth decrease transpiration loss whereas increased root enablesthe plant to tolerate drought by increasing water absorption from deeper layers of the soil.
Other than this anti-ozone chemical like Ethylene diurea (EDU) is also becoming popular in the dryland agriculture to suppress the effects of toxic levels of ambient ozone on the several fields and forage crops.

Assured benefits of transpiration suppressants and plant growth regulator to the rainfed/ dryland crops

- Optimized yield levels
- Better crop growth
- Normal sized grains
- Improved seed quality
- Reducing number of irrigations
- Monitoring crop loss with limited inputs
- Minimizing irrigation frequency and saving water through drip irrigation (eg. Cetyl alcohol and / Hexadecanol)
- Monitoring / managing drought
- Arresting fast receding soil moisture for better growth and yield of rabi crops
- Very useful for farmers with minimum irrigation facilities
- Saving large nurseries when water is scarce in summer months

Conclusion
The transpiration suppressants and plant growth regulators can be used to optimize yield levels under uneven and infrequent rainfall situations of dryland farming for better crop growth, yield, seed quality and higher economy. The nutrient uptake and water use efficiency will also be increased by the use of various anti-transpirants. But, the adoption of anti-transpirants to the farmer's field is very low which if could be followed then only the sustainable yield of dryland crops seems feasible. This practice escapes drought to some extent and is very useful for farmers with limited irrigation facilities. Therefore, there is a further need of extensive research works on the use of proper sources, concentrations and frequencies of transpiration suppressants for different crops in dryland areas. The easy access and availability of the chemicals and especial training needs to the farmers are the subjects to be given due attention to adopt the practice of transpiration suppressants in large coverage. This approach could make the soils of rainfed areas more productive for long-run.

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