



Climate resilience in litchi (*Litchi chinensis*) orchards in Bihar through soil manipulations

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ABSTRACT

Climate change is being evidenced in form of increased uncertainties and extremities of weather including heat waves and drought. Litchi is a subtropical fruit by origin and natural abundance. Litchi being cultivated on the fringe of tropics and subtropics in India is very sensitive to further warming. The event of drying of litchi tree in some orchards in Muzaffarpur district of Bihar, India during 2016 warranted the need to explore management options to induce climate resilience. Litchi orchards including those where drying of litchi tree was observed were identified and grouped based on different management practices. Soil analysis revealed that pH ranged from 7.8 to 8.3 where as EC was $<0.2 \text{ dS m}^{-1}$. Across the different management practices, available nitrogen was in the very low category ranging from 74 kg ha^{-1} to 210 kg ha^{-1} . Available P was in the range of 7 to 10.2 kg ha^{-1} and available K in the range of 98 to 218 kg ha^{-1} . Micronutrients viz., Zinc, was deficit in soil where as Boron and Sulfur were found adequate in most of the orchards. Soil moisture, permanent wilting point (PWP) and soil temperature at the depth of 5 and 15 cm revealed extreme soil dryness and high temperature, relatively less under orchards receiving FYM or, pond sediment. Soil moisture in the orchards was near the PWP where as soil temperature (5 cm) in open was 41 to 42°C . Very poor rainfall (5.6 mm) between Oct 2015 to April 2016, shallow soil, extreme dryness led break in capillarity between upper soil and lower sand layer, elevated soil temperature coupled with moisture stress were established as reasons for drying of Litchi trees. Under similar soil depth, no drying of trees was observed from the orchards in which either FYM was applied on annual basis or incorporation of pond soil in root zone was routine practice which was corroborated in terms of better moisture and temperature conditions during April, 2016. More events of extreme dryness during October to April were witnessed in post the year 1980 in historical weather data. Climate change projections under representation concentration pathways (RCPs) 8.5 indicate rainfall reduction of about 76% in November to April, though annual rainfall is likely to increase by 36%. Temperature increase to the tune of 2.9 to 4.3°C by 2070, more during April coupled with reduced rainfall poses very high risk on litchi cultivation in traditional belt. Therefore soil manipulations including regular application of FYM, incorporation of pond sediment in orchards on shallow soil, litchi leaf mulching, early irrigations are recommended for moisture and thermal buffering thus greater climate resilience in litchi.

1. INTRODUCTION

Year 2015, 2016 and 2017 were declared three

warmest years in the recorded history of climate data (WMO, 2018). Evidence of warming is mounting and

there is almost unanimous opinion that tropics will suffer more due to climate change despite of moderate observed trend as well as projections of climate change. Reasons are complex comprise economic, geographic and meteorological factors including relatively narrow but high base temperature ranges (Martin, 2015; Dillon *et al.*, 2010). Even the small deviation from the base range of temperature is likely to have significant effect. Higher dependence on natural resources, low economic buffering capacity because of gross lack of alternate means of income renders the tropics more vulnerable to climate change. Global warming has further extended the tropical region over last several decades' (Lovett, 2007).

The expression of climate change includes extreme rainfall events, increased frequency of droughts and floods, more fluctuation in temperature, heat waves and storms. Climate change projections under different RCPs indicate temperature increase of upto 4°C while CO₂ concentration might increase to 850 ppm by the year 2100 under RCP 8.5 (IPCC, 2014). The regional projections indicate more warming (Kumar *et al.*, 2010; Kumar *et al.*, 2010a). Increase in temperature increases photosynthetic activity and root conductance to certain extent, but further increase inactives enzymes thereby reduces the plant ability to cope with heat stress. The ratio of photosynthesis and respiration must be high in order to achieve high growth and yield (Moretti *et al.*, 2010). It is often assumed that perennials have high resistance to climatic aberration but once the resistance limit is tipped, it may become catastrophic. The crops which are presently grown on warmer zone of optimal thermal regime are most vulnerable to further warming.

Litchi (*Litchi chinensis* Sonn., Sapindaceae) is a sub-tropical evergreen perennial fruit being commercially cultivated in few subtropical and tropical countries in the world. India is a major litchi growing county, ranks 2nd in area and production just behind China and together account for more than 90% of the world litchi production. Largest hub of litchi production in India is in north Bihar plain adjoining Himalayan foothills. With area coverage of about 32000 ha (2014-15) out of total Litchi area of 86000 ha (2016-17), Bihar is one of the leading state in terms of area as well as production and contributes about 38% to total litchi production (523.3 thousands tones) in India. Warm humid summer and cool dry winter are considered best for good

quality litchi production. Water stress is major limitation for commercial cultivation of Litchi in India. Soil moisture near to field capacity or higher than 50% of field capacity is must for quality production. Warm and dry spell during flowering are often encountered in traditional belt of litchi in India which often desiccate pollen, reduces bee activities and result in poor fruit set (Kumar and Nath, 2013). A well distributed annual rain fall of 1200 mm is sufficient for good production but under skewed distribution of rainfall, irrigation is required for successful commercial production (Singh, 2012). Mean temperature range for optimum growth and fruiting of litchi has been reported 15 to 25°C (Menzel, 1989), however being perennial and adapted to warmer climate it can tolerate more than 45°C for a short period. The variation in weather is likely to increase under climate change condition.

Though litchi has been commercially grown successfully in the warmer climate mostly on the fringe of tropics and subtropics, by the origin and natural abundance, it is subtropical. In warmer climate, flowering is believed to be induced by moisture stress unlike to the cold stress in subtropical condition. To induce flowering there is practice of minimizing irrigation during late winter to early summer (Dec to Feb). Contrary to that, abundant flowering has been observed in Muzaffarpur district of Bihar, despite of rainfall during this period. It seems cool winter in this fringe zone between tropics and subtropics is probably sufficient to induce flowering in litchi. Heat and water deficit are two common stresses for litchi mainly during fruiting season.

Being grown on fringe (warmer) climate in India, litchi is vulnerable to further warming under climate change conditions. Irrigation has been traditionally used for microclimate modification under extreme heat stress. Though pollen desiccation, sun burn, fruit drop because of heat stress are common observed phenomena, there were reports of drying of full grown tress in some orchards during end of April, 2016 which was a rare occurrence. During the same period there were full bloom orchards in the proximity. This paper systematically investigates the reason for drying of litchi trees and recommendations for better climate resilience.

2. MATERIALS AND METHODS

Study Area

The study was conducted in Bochaha block of

Muzaffarpur districts of Bihar, India, where drying of litchi trees were reported. The Bochaha block in particular is known for producing some of fine quality of Sahi cultivar litchi in India. An investigative study was done on the site of reported drying as well as nearby orchards where no such problem was observed. In this area litchi has been cultivated on recent alluvium with coarse texture and calcareous soil. Being recent alluvial, these soils are very poor in organic matter and nitrogen. The average annual rainfall is about 1200 mm out of which about 90% is received during south west monsoon. Mean monthly temperature ranges from 15 to 36°C with minimum during January and maximum during May. Daily maximum temperature reaches upto 43.5°C where as daily minimum may goes below 4°C. Litchi is the main commercial horticultural crop of the area and fruiting orchards of various ages (5 to more than 100 years) can be observed.

Sample Collection

Daily weather data of TCA Dholi campus of Dr. RPCAU Pusa which is located at 20 km from the study sites were used. For detail investigation for drying of orchards, a team of experts from ICAR-National Research Centre for Litchi visited the site. Initial apprehension of infection with *Alternaria* spp. was shortly ruled out after laboratory analysis. During the same period of reported drying, there were orchards in proximity with good fruit set which put a curious case of investigation. Based on the information collected from orchards owners and traders involved in management of orchards, Litchi orchards of age 15-20 years were grouped in to 5 classes based on different management practices. The details of management practices are given in Table 1. Soil samples were collected from each management

group and analyzed for physicochemical properties.

Chemical fertilizers were applied in form of Urea (N: 46%), DAP (N: 18%, P: 46%) and MOP (K: 60%). Fertilizer and FYM were applied only in mid to end of June, after harvest of litchi fruits. All the orchards selected for study had access to a minimum irrigation during fruiting season. Four composite soil samples (0-15 cm) were collected from each management group for chemical analysis and 10 profile samples were collected, 2 from each management group at 15 cm intervals up to depth of 45 cm, sand layer was encountered below it. Bulk density of surface soil (1-15cm) was determined using core sample. Profile samples were used for determination of moisture, textural analysis and PWP. Soil temperature was measured for two consecutive days, 27-28 April, 2016, using portable soil temp probe at 5 and 15 cm depth from six locations including sites representing litchi orchards under 5 different management groups and one open barren site without vegetation at 14.00 hrs for two days (27-28 April, 2016). Soil moisture content at each 15 cm depth was determined using gravimetric method. Moisture content at pressure of 15 bars was also determined and referred as PWP. Daily weather data collected from a weather station located at distance of about 20 km was interpreted. Historical weather data of nearest IMD grid was also used for trend analysis. For projected climate change data, the daily weather data files of 30 arc-second derived from WorldClim using the MarkSim, for the year 2070 with 30 replications under RCP 8.5 was analysed as compared to baseline period weather data.

Sample Analysis

Soil separates was determined by international pipette method, soil moisture by gravimetric method,

Table: 1
Details of different management practices considered for the study

Code	Management details
M1	Litchi orchards receiving only chemical fertilizer @ N: 0.7 to 1 kg, P: 0.5-0.7 kg and K: 0 to 1 kg per tree every year. Litchi leaves and litter falls were periodically removed.
M2	Litchi orchards receiving FYM@ 50 to 60 kg alongwith chemical fertilizer @ N: 0.5 to 1 kg, P :0.5-0.7 kg and K: 0 to 0.5 kg per tree. Litchi leaves and litter falls were periodically removed.
M3	Litchi orchards receiving chemical fertilizer, @ N: 0.7 to 1 kg, P: 0.5-0.7 kg and K: 0 to 1 kg per tree every year. Leaf litters were used for mulching of trees since past 10-12 years.
M4	Litchi orchards receiving, FYM @ about 50 kg, chemical fertilizer @ N: 0.5 to 1 kg, P: 0.5-0.7 kg and K: 0 to 0.5 kg per tree every year and litchi leaf litters were used for mulching since past 10-12 years.
M5	Litchi orchards receiving pond sediment (clay enriched sediment) @ 150-200 kg per tree every alternate year and chemical fertilizer @ N: 0.7 to 1 kg, P: 0.5-0.7 kg and K: 0 to 1 kg per every year. Litchi leaf litters were periodically removed.

PWP by pressure plate apparatus (Pressure-15 bars) on disturbed soil samples, soil pH by glass electrode, EC by electrical conductivity meter, Mineralizable N by using alkaline KMnO_4 (Subbaiah and Asija, 1956), available P by Olsen method as described by Black (1965), Sulphur was determined by turbidimetric method, Zn by DTPA extraction method using Atomic absorption spectrophotometer and B using colorimetric method. The methodology described in Methods manual, Soil testing in India (Anonymous, 2011) was followed for laboratory analysis. Soil temperature was measured at two depth *viz.*, 5 cm and 15 cm using portable penetrable temperature probe at 14.00 hrs. One-way ANOVA and Duncan Multiple Range Test were performed in Excel for comparison among management group. Trend analysis including M-K test was done in excel (Gomez and Gomez, 1984).

3. RESULTS AND DISCUSSION

Soil Texture and Organic Matter

Soil texture across the all management group was sandy loam with relatively higher clay content in case of management receiving pond sediment. Clay content in pond sediment was 55 to 60% where as native soil contains 9-10% clay (Table 2). The effect of application of organic input in term of FYM, litchi leaves and pond sediment was visible in terms of surface (0-15 cm) soil organic carbon which was significantly higher in this management group. Relatively higher organic carbon content in the soil receiving pond sediment may be attributed to incorporation of relatively carbon rich sediment as well as favorable micro-environment for root growth thus higher residue incorporation, which could not be corroborated in this investigation. The increased organic carbon in response to FYM and residue incorporation has been reported (Kumar *et al.*, 2014). Approximately 1.5 tones of pond sediment having clay in the range of 55 to 60% has been applied and mixed in surface soil which is estimated to increase

clay content of the native soil by 3-4% in an area of about 80 m² covering almost all canopy spread over 5 m radius.

The increase in clay content of soil due to incorporation of pond sediment, can be estimated for a typical soil having native clay content of 10%, total pond sediment incorporation over the years (incorporated @ 150 kg for 10 years out of 25 years) is 1500 kg, clay content in pond sediment is 55%, and bulk density of soil is 1.4 g cm⁻³, targeted spread radius of 5 m and targeted depth of 0.15 m:

Spread area $A = \pi r^2$, *Volume of soil of top 0.15 m* = $D \pi r^2 \times 0.15 = 3.14 \times 5^2 \times 0.15 = 11.775$ cubic meter, *Mass of the soil* $\text{mass} = 1400 \times 11.775 \text{ kg} = 16485 \text{ kg}$, *Clay content in 0-15 cm soil* = $16485 \times 0.1 = 1648.5 \text{ kg}$, *Clay added by means of 1500 kg of pond sediment having 55% clay* = $1500 \times 0.55 = 825 \text{ kg}$, *Total amount of clay* = $1648.5 + 825 = 2473.5 \text{ kg}$, *Total amount of soil* = $16485 + 1500 = 17985 \text{ kg}$, *Clay % after incorporation of pond sediment* = $\left(\frac{2473.5}{17985} \right) \times 100 = 13.75\%$.

Though the targeted depth was upper 0.15 m but due to the addition of pond sediment the increase in soil depth is expected even with the same bulk density.

$$\text{Final soil depth (m)} = \frac{17985}{1400 \times 2.14 \times 5^2} = 0.163 \text{ m}$$

Clay content increases by 3.75% in top 16.3 cm soil layer instead of 15 cm.

Soil Nutrient Status

Soil pH ranged from 7.1 to 8.2 which were typical of calcareous soil of Muzaffarpur district. The pH range was higher contrary to reported pH requirement of Litchi in most of the literature. Soil across the management practices was poor in organic carbon with relatively higher organic in orchards receiving FYM (M4) or pond sediment (M5). Electrical conductivity was less than 0.2 dS m⁻¹. Though the effect of soil manipulation and management was visible, soils of the orchards under different management group were poor in fertility. Available

Table: 2
Texture, organic carbon, pH, electrical conductivity and bulk density of soil

Management group	Sand (%)	Silt (%)	Clay (%)	Organic carbon	pH	EC (dS m ⁻¹)	BD (g cm ⁻³)
M1	74.3ab	16.3ab	9.4a	0.25a	8.2ab	0.14ab	1.48a
M2	73.5ab	16.9ab	9.6a	0.31bc	7.8a	0.09a	1.39b
M3	72.4ab	17.5a	10.1a	0.29b	8.1ab	0.18b	1.51a
M4	75.0b	14.3b	10.7a	0.32bc	7.9ab	0.10a	1.42b
M5	71.8a	14.8b	13.4b	0.33c	8.3b	0.19b	1.37b
Mean	73.4ab	16.0	10.6	0.30	8.06	0.14ab	1.43

nitrogen was in poor category with relatively higher under orchards receiving FYM (M4) and lowest under orchards receiving only chemical fertilizer (Table 3). High variability in available P and K was observed (Table 3). Available P was also in poor category except in M2 where it was in medium category. With high variability, available K was also in low category across all management groups. Boron was found sufficient, where as Zn was insufficient. Despite of very poor organic carbon and nutrient content, these soil supports annual as well as perennials mainly because of fresh deposition of sediments during floods and application of external source of nutrients. Though the poor soil nutrient status may be attributed for poor growth and production; it could not identified as main reason for drying of litchi orchards.

Soil Moisture

Soil moisture at different depths were near to or less than PWP (Table 4) at the end of April, 2016. Soil moisture at 0-15 cm, 15-30 cm and 30-45 cm ranged from 6.6-12.4, 8.4-11.5, and 7.8-10.3%. PWP and moisture content in treatment receiving pond sediment was observed higher which may be attributed to modified texture due to incorporation of clay rich sediment. The higher canopy coverage would have

Table: 3
Available plant nutrients in soil under different management group of litchi orchards

Management type	Avl N kg ha ⁻¹	Avl P kg ha ⁻¹	Avl K kg ha ⁻¹	S (ppm)	Zn (ppm)	Boron (ppm)
M1	74.1a	7.2a	98a	15.6a	0.2a	0.5a
M2	194.1b	15.3b	124a	24.6b	0.31a	1.1b
M3	88.6a	8.3a	133a	17.8a	0.32a	1.1b
M4	210.8b	10.2ab	98.9a	21.4ab	0.28a	0.9b
M5	145.4c	8.6a	218b	18.7a	0.19a	0.8b
Mean	142.60	9.92a	134.38	19.62	0.26	0.88

Table: 4
Permanent wilting point and soil moisture content at different depth in litchi orchards under different management group

	PWP (15 bar)			Moisture content		
	0-15 cm	15-30 cm	30-45 cm	0-15 cm	15-30 cm	30-45 cm
M1	7.8a	9.5a	8.2ab	6.6a	8.4a	7.8a
M2	8.3a	9.6ab	9.1a	10.5b	8.7a	9.3b
M3	9.12b	9.4a	8.3ab	8.4c	9a	8.6a
M4	9.4bc	10.4b	7.9b	9.5cb	10.5b	10.4c
M5	10.6c	10.1ab	8.7ab	12.4d	11.5b	10.3c
Mean	9.04	9.8	8.44	9.04	9.8	8.44

also help protect soil moisture in some of management group specially M5.

There was sand layer below 45-50 cm depth at most of the places of sampling. Very poor rainfall (5.6 mm) from Oct, 2015 to April 2016 as compared to normal (138 mm) was the main reason for drying of soil. Moisture deficit is one of the important stresses in plant which often cause wilting. In case of deeper soil (depth >90 cm), lower layer generally contain relatively higher and protected moisture which support the plant in case upper layer gets dried. This was unlikely in the present investigation as deeper layer was dry sand with very poor moisture holding capacity thus leaving upper layer isolated and drier. The moisture stress may be the reason for drying but cannot be pin pointed as such, because in many perennials, the PWP is moisture content equivalent to pressure as high as 25 bars.

Soil Temperature

Though the soil temperature data was collected post drying of orchards in which high radiation penetration due to leaf shedding would have affected the soil temperature, nevertheless the soil temperature data gave an indication of temperature stress on plant roots. Soil temperature was lowest under the orchards receiving pond sediment (Fig. 1). This may be attributed to the relatively higher moisture content, better plant canopy and overall microclimate of the orchard. The effect of different management practices on moderating soil temperature could be noticed (Fig. 1), though the magnitude of temperature might have been affected by extent of radiation penetration.

Soil temperature at 5 cm depth was as high as 41.6°C (Fig. 1) in open area which was just higher than the air temperature. Among the different management

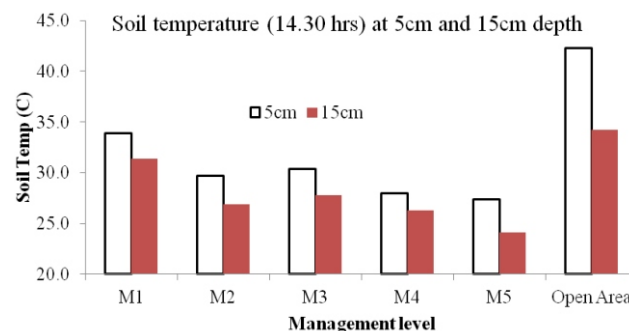


Fig. 1. Soil temperature (14.00 hr) at depth of 5 cm and 15 cm of litchi orchards under different management group (average of April 27-28, 2016)

group, highest soil temperature at 5 cm depth was observed in the orchard receiving only chemical fertilizer (drying orchards) and lowest under pond sediment incorporation. Soil temperature at 15 cm depth was lower as compared to soil temperature at 5 cm depth but it followed same trend and highest was in open area followed by the orchard under M1 (Fig. 1). The high soil temperature may be result of elevated air temperature and low specific heat of dry soil. Air temperature was also typically higher during second half of April, 2016 (Fig. 2). Weekly air temperature of year 2014 to 2018 reveals abnormally high temperature during 15th to 17th week of 2016 (Fig. 2). Soil surface as well as profile was dried mainly due to very poor rainfall received during Oct 2015 to April, 2016. The rainfall during September, 2015 also was par below the normal (Table 5). Changed rainfall pattern are held responsible for frequent drought around the globe (Lobell *et al.*, 2011). Negative impact of severe drought on plant growth and production have been well documented (Yordanov *et al.*, 2000; Barnabas *et al.*, 2008). Plant with reduced root conductivity at higher temperature encountered very limited soil moisture thus failed to extract moisture. Heat stress restricts number and growth of roots which ultimately

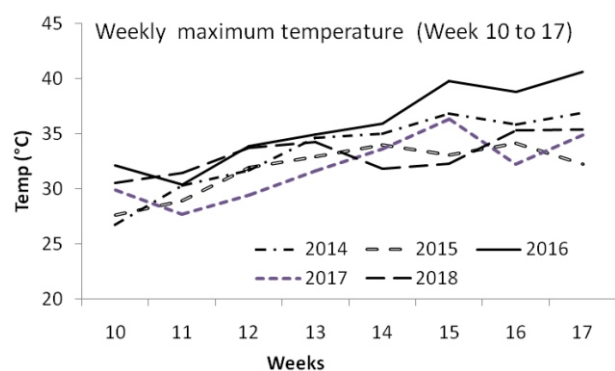


Fig. 2. Weekly maximum temperature from 10 to 17th week in different years

Table: 5

Rainfall received between Sept to next April during different years against normal rainfall

Rainfall	Normal	2013-14	2014-15	2015-16	2016-17	2017-18
Sept	233.8		129.4	155.8	319.2	44
Oct	74.7		81.6	2.4	34.6	3.5
Nov	12.7		0	0	0	0
Dec	7		2.2	0	0	0
Jan	10.7	9.5	8.4	0	0	0
Feb	13.4	32.4	1.2	2.1	0	0
March	5.5	10.6	32.5	0	10.6	0
April	15.8	6	33.2	1.2	63.6	41.4

limit the supply of water and nutrients, even if it is available (Huang *et al.*, 2012; Basiriad, 2000; Garg, 2003). The combined effect of soil moisture and high temperature stresses might have restricted the conductivity of feeder roots.

Very poor rainfall during Oct 2015 to April, 2016 was the main reason for extreme soil dryness. In this part of India, the October rainfall is not only very important for *rabi* crops but also good for perennials as this moisture remains longer in soil due to reduced evaporation loss during winter (Nov-Feb). One to two showers during March-April gives much needed boost to litchi under fruit development stage but during 2015-2016, total rainfall received between Oct to April was 5.6 mm as against long term normal of about 138 mm. Rainfall during Sept (156 mm) was also less than normal (234 mm). Farmer's or trader's ignorance who often manage orchards for 3 to 5 years on lease and, failure to sense the danger of heat and moisture stress were other reasons for drying of orchards. Farmers often ignore the perennial crops assuming high resistance against climate fluctuations. Though there were limited access but no irrigation was provided till the end of April, early irrigation would have averted the crisis by reducing moisture and temperature stress.

The effect of moisture stress gets multiplied if it is coupled with high temperature stress. Plant tries to stabilize tissue water content in response to the high temperature when ample quantity of water is available, but under dry condition, elevated temperature may be fatal (Machado and Paulsen, 2001). In tropical and subtropical condition, heat stress often coincides with water scarcity (Simoes-Araujo *et al.*, 2003). Weekly average of daily maximum temperature (Fig. 2) shows exceptionally high temperature during April 2016 which coincided with the fruit development stage. There were severe fruit drop alongwith drying of orchards. The combination of moisture and heat stress was therefore identified as main reason. The relatively better soil moisture and lower soil temperature in treatments receiving FYM and pond sediment helped plant cope with stress. There were no causalities in the orchards receiving irrigation before mid of April, 2016.

Historical Weather Data and Abiotic Stresses on Litchi

To check whether this combination of stress is unique or it has happened in the past, rainfall data of

1951 to 2007 and temperature data of 1969 to 2005 were analyzed for drought and high temperature stress during post rainy season. Total rainfall between Oct to next April plotted on yearly basis shows there were five years with rainfall less than 25 mm between Oct to April (Fig. 3). Out of these five years, 3 years received <10 mm and its lowest (5.6 mm) during 2016. All these five years were post 1980 (1981-82, 1984-85, 1991-92, 2000-01 and 2005-06). All the year with <10 mm between Oct to April were post 1984. From historical weather data, the increased event of moisture stress due to reduced post and pre rainy season rainfall is indicated post 1980. Though the M-K test rules out any significant trend in the Oct-April rainfall, more such events in recent past need to be checked in climate change perspective. The Weekly temperatures of 10 to 17th week for the five driest years (1951 to 2006) were compared with the maximum temperature for 2016 during the same period of the year. Maximum temperature during 14-17th week (April) of none of the identified driest year was as high as in 2016 except 1992. The Year 1991-1992 received very less rainfall (5.9 mm) from Oct, 1991 to April 1992 and Maximum temperature during 10 to 17th week were relatively higher, similar to the year 2016 (Table 6). The information on impact of these combined stresses of drought and heat could not be corroborated for 1992 as most of the litchi orchards facing this problem were not present during 1992. The rainfall and temperature data for the period of 2006 to 2013 could not be accessed therefore not included in this analysis.

Climate Change Perspective of Suitability for Litchi

There was greater number of years with very less rainfall during Oct to next April after 1980. There were

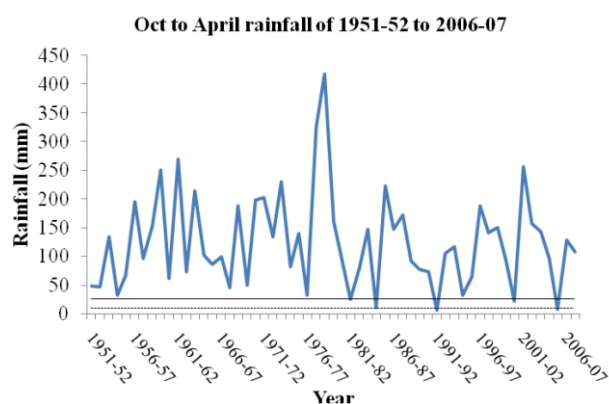


Fig. 3. Rainfall received between October to next April under different years (1951-52 to 2006-07) alongwith threshold line of 25 mm (solid line) and 10 mm (dotted line)

events of coupled moisture and heat stress which made a curious case of investigation for climate change and projections. The daily weather data files of 30 arc-second derived from WorldClim using the MarkSim, for 2070 with 30 replications under RCP 8.5 was analysed as compared to baseline period weather data. Overall increase in annual rainfall is about 37%, but off season rainfall (Nov to April) is likely to reduce by 76% (Fig. 4). The increased rainfall during monsoon may increase the frequency of flood where as reduced rainfall between Oct to April may lead to drought condition for *rabi* crops and perennials including litchi. Litchi generally irrigated during fruit development and maturity (April-May) will need more frequent irrigation under climate change condition due to reduced post rainy season rainfall and increase in maximum as well as minimum temperature. The projected increase in temperature over baseline period superimposed over the adjusted long term average of daily maximum temperature (Fig. 5) shows relatively higher increase (3.9 to 4.3°C) in maximum temperature during March-April. Any increase in maximum and minimum temperature

Table: 6

Weekly maximum temperature (10 to 17th weeks) during five different years between 1951-52 to 2005-06, and 2014-2018 identified based on Oct to April rainfall of <25 mm

Week No.	Weekly Maximum Temperature				
	1982	1985	1992	2001	2016
10	24.4	33.3	30.4	29.2	32.1
11	30.2	34.4	32.7	32.2	30.4
12	33.3	34.0	34.7	34.0	33.9
13	32.7	35.5	37.1	34.8	34.9
14	36.6	35.3	37.0	36.7	35.9
15	35.8	37.2	39.5	37.4	39.8
16	32.9	37.5	39.5	34.5	38.8
17	35.6	39.3	38.7	38.7	40.6

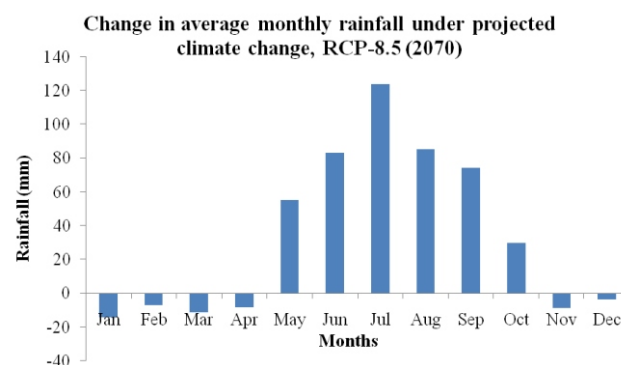


Fig. 4. Projected change in monthly rainfall by 2070, under RCP 8.5 (MarkSim)

during this period is likely to have negative impact on litchi production in Bihar as it is already grown on warmer side of optimal temperature range. The increase in soil temperature in response to elevated temperature is inevitable. Global warming is held responsible for change in soil temperature as well as precipitation patterns (Jungqvist *et al.*, 2014) though response of soil temperature is influenced by various soil and moisture regimes (Zhang *et al.*, 2005). The moisture stress can be overcome to some extent by means of irrigation but it will be difficult to cope with the temperature increase of more than 4°C especially during April. Irrigation will be required not only for plant uptake but more importantly for temperature moderation. Temperature during April 2016 surpassed the projected average temperature of the year 2070 under RCP 8.5 (Fig. 5). Reduced rainfall during Nov to April and increased temperature means very frequent drought and heat stress on litchi. Even flowering may become irregular and less predictable due to insufficient chilling under projected change. A series of morphological and biochemical changes takes place in plant at high temperature (Wahid *et al.*, 2007; Wahid and Close, 2007) including reduced cell division (Smertenko *et al.*, 1997), root conductance which ultimately results into restricted growth and performance.

So far no systematic study on high temperature extremes on litchi production and growth has been done but the present study indicates high vulnerability of Litchi in Bihar towards heat and drought stress. In case of poor rain fall during Oct to

March, and rising temperature, early irrigation (mid to end of March) may help plant cope the stress.

4. CONCLUSIONS

Shallow soil over sand layer below 45-60 cm depth, extreme dryness led break in capillarity between soil and bottom sand layer, elevated soil temperature coupled with moisture stress were established as reasons for drying of litchi trees. Application of FYM, not only helped improve plant yield but more importantly provided moisture and thermal buffering, could save orchards from drying under combined stress of moisture and high temperature. Micro site improvement through incorporation of pond sediment even in old orchards planted on shallow soil could provide necessary protection from extreme warming and drying. Climate change and projections indicates real challenge for suitability of litchi in north Bihar. Present traditional belt of litchi in India may turn less suitable under projected climate change and north wards shift may be a viable option. Therefore before planning new orchards in the fringe climate, the climatic trend and projections must be considered. Regular application of FYM, litchi leaf mulching, incorporation of pond sediment especially on coarse shallow soil, modified irrigation scheduling based on soil moisture and temperature measurement, irrigation during end of March to mid of April in case of less post monsoon rainfall are options to improve climate resilience of the system for sustainable litchi production.

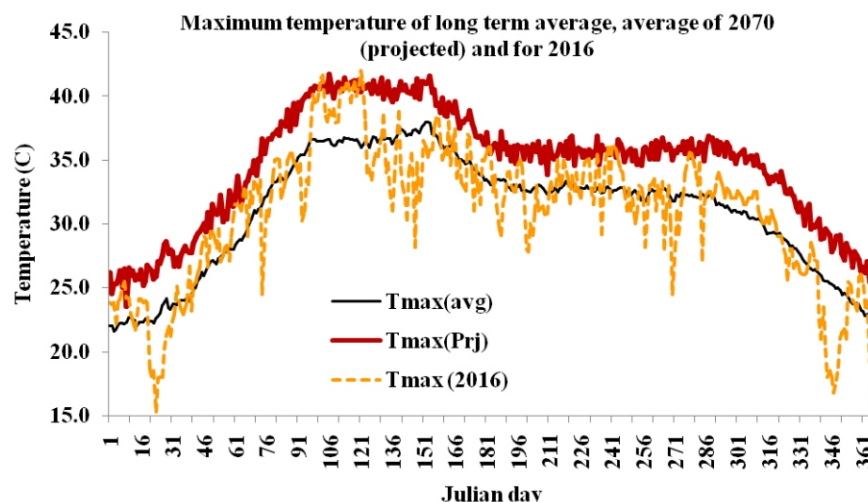


Fig. 5. Long term average maximum, projected maximum temperature, and maximum temperature during 2016

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