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A Review of impacts of climate change on crop Phenology and productivity

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Abstract
Changes in crop phenology and its interaction with the changing environmental conditions were highlighted as a basis for formulating reliable adaptation policies. Specific stages of growth (*i.e.* flowering and grain filling) are particularly sensitive to weather conditions and critical for final yield. The timing of the crop cycle determines the crop productivity. The crop phenology and productivity are influenced by both genetic and environmental factors with day length, temperature, moisture availability and humidity. Crop productivity is very less and one of the main constraint for low productivity is qualitatively short day nature making its yield formation stages coincides with terminal drought in a nutshell, in view of climate change effects, it is the need of the hour to address the physiological yield constraints by sincere effort for generating technology for realizing potential yield under rainfed condition. As global warming is continuous, change in climate particularly, rise in temperature coupled with elevated CO2, low and variable precipitation will have pronounced effect on crop phenology and productivity. The critical knowledge gaps related to effect of climate change on phenology and productivity of crop exists. Predicting the phenological events is a major challenge for assessment of the impact of an adaptation to weather vulnerability.

Keywords: phenology, climate change, plant responses, crop productivity and weather vulnerability

Introduction

Crop is being grown under rainfed situation and has been a highly risky venture with vagaries of monsoon, the interplay of other abiotic and biotic factors particularly, initial moisture stress, diurnal variation in temperature coupled with frost and foggy weather during reproductive growth phase and terminal drought. In such a situations of uncertainty, intra and inter annual variability in weather causes substantial fluctuations in crops productivity leading to the instability in production. On the other hand, in context of climate change, it has been revealed that the pulse crop in particular, have the potential to maximize the benefits of elevated CO2 arising out of climate change (effects) by matching the stimulated photosynthesis with increased nitrogen fixation. However, such positive results illustrate the importance of crop for food and nutritional security under the climate change scenario. Generally climate change is expected to trigger the changes in terms of phenology and physiology of the pigeon pea crop. As within genetic limits, crop yield is determined by the environmental factor therefore, any possible understanding of weather yield relationship may help determine the best time to apply specific practices in order to maximize yield. Production potential for agiven crop is strongly related to crop phenology which is largely sensitive to temperatures and photoperiod (McPherson *et al.*, 1985) [21]. Flower production in pulse in general, and pigeon pea in particular is profuse and flowering period appeared to be influenced by weather conditions. The extent of abscission of flower and pod may be due to adverse climatic factors *viz.*, temperature, diurnal variations in temperature, light intensity, relative humidity, wet or cloudy day's precipitation and its distribution *etc* (Mahta and Dave, 1931) [20]. Besides genetic factors, hormonal and nutritional imbalance and adverse climatic conditions are known to induce flower/pod shedding in grain pulses. Changes in crop phenology and its interaction with the changing environmental conditions were highlighted as a basis for formulating reliable adaptation policies. Specific stages of growth (*i.e.* flowering and grain filling) are particularly sensitive to weather conditions and critical for final yield. The timing of the crop cycle determines the crop productivity. In the present study the natural thermal variations for phenological phases were simulated by sowing the crop at different dates. Changes in crop phenology and its interaction with the changing environment were highlighted as a basis for formulating reliable adaptation policies. Specific stages of growth (*e.g.* flowering, grain filling) are particularly sensitive to weather conditions and critical for final yield. The timing of the crop cycle (agro phenology) determines the crop productivity.

The climate change and its impacts on crop phonological behavior and productivity are well marked in various crops which are reviewed in this article and some of them are listed in the following Table 1.

Table 1: The existing research findings of climate change and its impacts on phonological behavior and productivity of different crop

Sl. No.	Name of the Researchers	Crops	Study parameters
1.	Laxman *et al*. (1971) [18].	Pigeonpea	**a) Phenology and dates of sowing** Observed that planting height and number of branches were significantly increased, but the effective pod bearing length was significantly reduced, resulting in no difference in the number of pods and yield per plant at various dates of sowing
2.	Gooding (1960) [14] and Riollano *et al.* (1962)	Pigeonpea	Reported significant influence of date of sowing on crop Phenology. Time of sowing, because of its effect on the vegetative and reproductive phases of the crop are an important factor influencing crop duration.
3.	Ahlawat *et al.* (1975) [1].	Wheat	They concluded that end of June planting was better than July, since cooler weather at later stage delayed maturity. Earlier planting grows normally and harvested well in time to allow to taken up for a successful crop of wheat *Rabi* season. Long duration varieties were often destroyed by frost in November.
4.	Dahiya *et a1*. (1974) [4].	Pigeonpea	Data showed that with 16th June and 16th July planting of short duration variety, early planting gave higher yield, while in late sown crop 'vegetative sink' suffered more than 'generative sink' due to reduction in plant height and width, thus giving higher harvest index.
5.	Venkatarathnam and Green (1979) [32].	Pigeonpea	The results revealed that the late maturing type produces more total dry matter as compared to the medium and early maturing type. Further observed that the taller plants (89.95 cm) in the late maturing cultivar NR (WR)-15 and a shorter plants of 63.0 and 49.5 cm were observed in medium (C-11) and early (T-21)maturing varieties, respectively
6.	Narayananan and Sheldrake (1979) [22].	Pigeonpea	Observed higher dry matter production by late maturing genotypes than early maturing genotypes. The cv. ICP 7065 (late) produced the highest dry matter (7098 kg ha-1), as compared to medium types C-11(6297 kg ha-1), ICP-1 (6026 kg ha-1) and early types T-21 (4534 kg ha-1).
7.	Magadum (1982) [19].	Pigeonpea	The variety C-11 recordedsignificantly higher plant height (72.5 cm) and RG-21 the lowest (59.9 cm) and interestinglysimilar trend was observed in TDM. However, the maximum dry matter production in C-11(18.42 g plant-1), where it significantly lower in RG-21(15.69 g plant-1) followed by T-21(13.34 g plant-1).
8.	Bhat *et al.* (1983) [4].	Pigeonpea	The varieties TS-136-1was found superior with respect to grain yield and also recorded highest plant height (93.08 cm), number of leaves (93.20), branches plant-1 over rest of the genotypes studied.
9.	Summerfield and Lawn (1987) [29].	Mungbean	Reported that late maturing cultivars are better able to tolerate adverse growing conditions, such as periodic moisture stress, water logging and mild frost. Longer duration types have the time and phenological plasticity to recover from stress.
10.	Ravindranathreddy *et al.* (1997)	Pigeonpea	They reported that cv. LGR-30 recorded the highest plant height (174 cm) and more number of branches plant-1 (15.1) as compared to all other genotypes studied
11.	Thakur *et al*. (1997) [17].	Pigeonpea	Observed that cv. JA-3 recorded the highest plant height (170 cm), number of branches plant-1 (26) ascompared to other cultivars tested.
12.	Carberry *et al.*, (2001) [7].	Pigeonpea	The results showed that cultivars previously reported relatively insensitive to photoperiod infact were highly sensitive. Flowering in short-duration cultivars was delayed up to 100 days when day length in the photoperiod-inductive phase exceeded a critical value. Medium and long duration cultivars delayed flowering over 150 days in response to photoperiod. **b) Flowering and podding behaviour with different date of sowing**
13.	Akinola and Whiteman (1975) [2].	Pigeonpea	Reported the existence of differential sensitivity of phenology to day length among cultivars and identified quantitative short day, day neutral and intermediate photo periodic forms. Fifty per cent flowering in variety UQ-l and UO-38sown between Sept.1, '70 to 19th Jan. '71 declined from 219 days for 1st sowing to 115 days for the January sowing. For UO-37 and UQ-39 the average pre flowering duration was 86 and 74 days for early and late September sowings,
14.	Sharma *et al.* (1981)	Pigeonpea	Photoperiod response and maturity aspects of pigeonpea, that there are at least four major photo period response groups and classified into ten group based on maturity range (days to 50% flowering from 60 to 160 days).
15.	Bhat *et al.* (1989) [5].	Pigeonpea	Reported the diversion of carbon assimilates during the pod growth to stem and other storage organs. Decline in photosynthesis rates and other physiological anabolic process during onset of pod setting has been attributed for flower and pod drops. Further opined that there may be vascular limitation for supply of assimilates to pods during pod setting periods. In a qualitative short-day response to photoperiod, floral initiation does not occur above a certain photoperiod and the plant initiates only when photoperiod falls below this critical photoperiod.
16.	Chetia and Ram Kumar (2005) [8].	Pea	High temperature during reproductive phase resulted in reduced number of seeds pod-1. The photo thermal unit received during the vegetative stage had a significant positive correlation with yield. Whereas, it had a significant negative correlation with yield as well as with pods/plant and seeds pod-1 during reproductive phase of the crop. c) **Growth and developmental aspects**
17.	Pandey (1980) [23].	Pea	Showed that peak crop growth occurred between the onset of flowering and early pod formation, when canopy was fully developed and captured solar radiation efficiently. Total dry matter production in early genotypes ranged from 7.7 to 12.1 tonns ha-1. Off which 47 to 77% was produced after onset of flowering
18.	Nagamani *et al.* (1995)	Pigeonpea	The results revealed significantly higher plant height (116.93 cm) with ICPL-8863 (Maruti) as compared to LRG-30 (105.63 cm). However, ICPL-8863 produced significantly lower number of branches (8.3 branches plant-1) as compared toLRG-30 (10.2 branches plant-1).
19.	Bhattacharya and	Pigeonpea	Observed that, during flowering period of normal sown crop, leaf area and total dry matter are major traits

	Sharma (2001) [6].		to restrict flower drop, whereas under late seedling, root and total dry matter, leaf area and specific leaf weight restricts the flowerdrop. (20.45 g) as compared to other treatments.
20.	Dekhane *et al.* (2017)	Rice	They found that the combination of seedling dip in azotobacter + vermiwash 2 per cent + banana pseudo stem sap 2 per cent was the most effective with higher plant height (118.5 cm) and number of tillers (19.7) compared to other individual treatments.
21.	Maheswari *et al.* (2017)	Lablab Beans	Pot studies enhanced the effect at the end of sixth week with higher shoot lengths (56.24±0.14 cm), length of internodes (9.40±0.17 cm), number of leaves (20.88±1.01) and leaf surface area (18.59±0.24 cm^2) as compared to other treatments.
22.	Patel *et al.* (2017)	Fenugreek	The treatment pulse magic at 2 per cent exhibited higher plant height (35.5 cm), number of branches (5.23), leaf area (1.60 dm^2 $plant^{-1}$) and total dry matter accumulation (23.74 g $plant^{-1}$) as equated to other treatments
			b) Physiological parameters
23.	Thakur *et al.* (2017)	Blackgram	Observed that soil application of FYM at 15 t ha^{-1} + NPK at 75:75:50 kg ha^{-1} + panchagavya at 3 per cent foliar spray recorded the highest leaf area index (1.03)
24.	Pramesh *et al.* (2006) [25].	Pigeonpea	Var., ICPL-87119recorded significantly highest plant height (194.2cm) and branches per plant (25.3) than other varieties like Jawahar-4, BDN-2 and Asha, while BDN-2 recorded significantly lowest plant height (178.6 cm) and branches per plant (20.30).
25.	Dhanoji and Patil (2011) [11].	Pigeonpea	Significant decrease in yield was noticed with late sown crop and was mainly attributed to reduced flower production and pods per plant. The maintenance of more LAI and dry matter accumulation in early sown crop resulted in more yield. It might be due to higher sink to sources ratio. The reduction in potential sink size *i.e.* pods per plant, flowers per plant in late sown crop would be due to low precipitation and temperature especially during reproductivegrowth phase of the crop.
			d) Yield and yield attributes with date of sowing
26.	Kaul and Sekhon (1975) [16].	Pigeonpea	Significant reduction in grain yield with delay in sowing beyond June 15th was due to reduction in plant height, pods plant-1 and total dry matter production. However, delayed sowing gave a higher harvest index due to a sharp decline in dry matter production.
27.	Sheldrake and Narayanan (1979) [22].	Pigeonpea	The superiority of C-11, which gave a higher yield of 1710 kg ha-1 followed by ICPL-1 (1494 kg ha-1) and both these cultivars belong to medium maturity group. Early (T-21 and Pusa Ageti) and late (ICPL-7065 and NR(WR-15) cultivars failed to give higher yield because of lower number of seeds per pod and reduced test weight. C-11 recorded higher number of seeds per pod and also higher harvest index as compared to early and late maturity cultivars.
28.	Faroda and Singh (1980) [13].	Pigeonpea	The result shows that cv. T-21 was found to be most suitable for June planting and UPAS-120 for July planting. The maximum yield was obtained with June planting and minimum yield with July planting
29.	Wallis *et al.*, 1981 [34].	Rice	Photoperiod insensitive variety gave maximum yield with a population of four lakh plants per hectare with September sowing
30.	Desai *et al*. (1990) [10].	Pigeonpea	Observed that the pigeonpea cv. t-15-15 recordedthe highest seed yield (20.79 q ha-1) as compared to rest of the genotypes tested cv. Azadwas found significantly superior with 18.21 q ha-1 grain yield followed by Amar (15.46 q ha-1) and Bahar (15.97 q ha-1). Early planting on 16th July was found significantly superior over delayed plantings. Maximum plant height (237.13 cm), number of branches (20.20) andnumber of pods (60.20) per plant was obtained with 16th July planting with 19.78 q ha-1 of yield.
31.	Vijayalaxmi (2012) [32].	Pea	Stated that under late seeded condition, pea crop was exposed to high temperature during flowering and seed filling stages which expressed reduction in mean membrane stability index (19.3%),plant height (60.2%), total biomassyield (61.7%), seed yield (68.9%) reduction and other traits. Among the genotypes studied, KPF 103,DMR 15, IPFD 4-6, were found to be having comparatively higher amount of resistancetowards high temperature stress. IPFD 99-7, IPFD 3-17, IPFD 1-10, and DPR 13 wereadjudged to moderately resistance for high temperature stress as they were having more than75.0 per cent yield stability index.

Conclusions

In order to realise potential yield of crops early sowing may be practiced as yield largely influenced by crop duration. All most major Crops are photo period sensitive and exposure to favorable short day photoperiod makes plants to switch into reproductive phase with late sown crop resulting poor yield. Sowing of crops, should be done June or July month at the onset of the monsoon sowing of crops is done. Late sowing causes considerable reduction in yield. Because the fluctuation in day and night temperature during reproductive phase might be responsible for inducing more flowers shedding which adversely affects yield potential of the crop.

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