10. Sinha, S. and Swaminathan, M. S., The absolute maximum food production potential in India – An estimate. *Curr. Sci.*, 1979, **45**, 425–429.
11. Evans, L. T., Wardlaw, I. F. and Fischer, R. A., Wheat. In *Crop Physiology* (ed. Evans, L. T.), University Press, Cambridge, 1975, pp. 101–149.
12. Asana, R. D. and Williams, R. F., The effect of temperature stress on grain development in wheat. *Aust. J. Agric. Res.*, 1965, **16**, 1–13.
13. Wattal, P. N., Effect of temperature on the development of the wheat grain. *Indian J. Plant Physiol.*, 1965, **8**, 145–159.
14. Al-Khatib, K. and Paulsen, G. M., Photosynthesis and productivity during high temperature stress of wheat genotypes from major world regions. *Crop Sci.*, 1990, **30**, 1127–1132.
15. Howarth, C. J. and Ougham, H. J., Gene expression under temperature stress. *New Phytol.*, 1993, **125**, 1–26.
16. Abrol, Y. P. and Ingram, K. T., Effect of higher day and night temperatures on growth and yield of some crop plants. In *Global Climate Change and Agricultural Production* (eds Bazzaz, F. and Sombroek, W.), John Wiley, NY and FAO, Rome, 1996, pp. 123–140.
17. Burke, J. J., High temperature stress and adaptation in crops. In *Stress Response in Plants: Adaptation and Acclimation Mechanisms* (eds Alscher, R. G. and Cummings, J. R)., Wiley-Liss, New York, 1990, pp. 295–309.
18. Sorensen, J. G., Kristensen, T. N. and Loeschcke, V., The evolutionary and ecological role of heat shock proteins. *Ecol. Lett.*, 2003, **6**, 1025–1037.
19. Sun, W., van Montagu, M. and Verbruggen, N., Small heat shock proteins and stress tolerance in plants. *Biochim. Biophys. Acta*, 2002, **1577**, 1–9.
20. Sanchez, Y. and Lindquist, S. L., HSP 140 is required for induced thermotolerance. *Science*, 1990, **148**, 112–115.
21. Katiyar-Agarwal, S., Agarwal, M. and Grover, A., Heat tolerant rice engineered by over expression of HSP 101. *Plant Mol. Biol.*, 2003, **51**, 677–686.
22. Penning de Vries, F. W. T., Brunsting, A. H. M. and van Laar, H. H., Products, requirements and efficiency of biosynthesis: A quantitative approach. *J. Theor. Biol.*, 1974, **45**, 339–377.
23. Mitra, R. and Bhatia, C. R., Bioenergetic considerations in the improvement of oil content and quality in oilseed crops. *Theor. Appl. Genet.*, 1979, **54**, 41–47; 429–437.
24. Bhatia, C. R., Mitra, R. and Rabson, R., Bioenergetic and energy constraints in increasing cereal productivity. *Agric. Syst.*, 1981, **7**, 105–111.
25. Mitra, R. and Bhatia, C. R., Bioenergetic considerations in breeding for insect and pathogen resistance in plants. *Euphytica*, 1982, **31**, 429–437.
26. Zahedi, M., McDonald, G. and Jenner, C. F., Nitrogen supply to the grain modifies the effects of temperature on starch and protein accumulation during grain-filling in wheat. *Aust. J. Agric. Res.*, 2004, **55**, 551–564.
27. Hirel, B. and Gallais, A., Rubisco synthesis, turnover and degradation: Some new thoughts on an old problem. *New Phytol.*, 2006, **169**, 445–448.
28. Shearman, V. J., Sylvester-Bradley, R., Scott, R. K. and Foulkes, M. J., Physiological processes associated with wheat yield progress in the UK. *Crop Sci.*, 2005, **45**, 175–185.
29. Shrawat, A., Carroll, R., Taylor, G. J. and Good, A. G., Genetic engineering of rice to improve nitrogen-use efficiency. Abstr., In Nitrogen 2007 – An International Symposium on Nitrogen Nutrition of Plants, http:/biol.lancs.ac.uk/nif2007/book of abstracts.pdf
30. Theodoris, G. *et al.*, Nitrogen use efficient *Brassica napus* transgenic plants. Abstr., In Nitrogen 2007 – An International Symposium on Nitrogen Nutrition of Plants.
31. http:/www arcadiabio.com

Received 20 April 2007; revised accepted 28 February 2008

Impact of inter-annual climate variability on the phenology of eleven multipurpose tree species

P. S. Thakur[1,*], Vaishnu Dutt[1] and Anju Thakur[2]

[1]Department of Silviculture and Agroforestry, and
[2]Department of Basic Sciences, University of Horticulture and Forestry, Nauni Solan 173 230, India

The aim of this study was to find out the impact of climate change, if any, on the phenophases of 11 multipurpose tree species, growing as block plantation at one site, during eight years (1999–2006). Close monitoring of important fuel, fodder and timber tree species, has indicated significant shift (advancement) in the phenophases. Increase in monthly temperature above the normal has advanced leaf emergence and flower initiation phases. The climate change has prolonged the growth period of 10 out of 11 multipurpose tree species ranging between 31 and 46 days within eight years. The average maximum monthly temperature increased between 0.5 and 8.1°C, whereas annual rainfall declined from 1213.9 mm in 1999 to 969.4 mm in 2006. The average minimum monthly temperature remained unchanged during 1999–2006.

Keywords: Agroforestry, flower initiation phase, fuel-fodder, growth period, leaf emergence.

THE basis of the present investigation is the extension of an earlier study by Thakur and Kaur[1] on the phenology of different multipurpose agroforestry tree species, conducted in 1999. Phenophases, in fact, not only reveal growth behaviour of an individual tree species, but also indicate the magnitude and duration of growth. The phenological behaviour of many multipurpose tree species has been studied by earlier workers[1,2–6]. Climate indicators such as variation in temperature and rainfall closely influence phenophases of different tree species. The shift in phenophases seems to be the earliest observed response to fast-changing climate. This per se is the immediate impact of warming on the physiology of tree species[5,7]. This trend certainly will have long lasting and serious consequences both for plants as well as wildlife that survive on already lesser available resources[8,9]. Studies in the past have indicated that the climate change has produced noticeable effect on phenophases in plants[10–12]. Implications of global warming and climate change on flora and fauna, including production ability of food crops, have been the hot topic of discussion and debate at both national and international level during the last decade. Alarmed by the possible adverse impacts of global and regional climate change on flora and fauna, there has

*For correspondence. (e-mail: thakurps2005@yahoo.com)

been serious concern world over in understanding vulnerability of agricultural, fruit and tree crops and finding short and long-term strategies to reverse the negative effects. In this direction the ICAR has already launched a network on climate change in different ICAR institutions as well as State agricultural universities in the country from the latter half of the 10th Five-Year Plan, to indicate the impacts of climate change on Indian agriculture. The Intergovernmental Panel on Climate Change (IPCC) in its Fourth Assessment Report (AR 4)[9] has already indicated warming trend during the 20th century and its repercussions on biodiversity and existing flora and fauna. The report gives greater attention to the integration of climate change with sustainable development and the interrelationships between mitigation and adaptation with special mention of regional issues, uncertainty and risks, climate change and water. Climate change in the form of elevated carbon dioxide, drought and extreme temperature will not only result in drastic decline in production potential of annual and perennial crops, but may cause elimination of some of the important germplasms[8,9]. There is no information as to how the phenophases of multipurpose tree species will undergo shift with changing climate in Indian conditions. This study was, therefore, undertaken to delineate the impacts of climate change during eight years (1999–2006) on phenophases as well as growth period of 11 multipurpose agroforestry tree species planted at one site in the arboretum.

The experimental site represents a transitional zone between the subtropical and sub-temperate regions in western Himalayas, located between 30°51′N lat. and 76°11′E long., with an elevation of 1200 m amsl. The area receives annual rainfall of 1150 mm, most of it during the rainy season from July to August each year. Soil of the experimental site is sandy loam.

The block plantation of 11 multipurpose tree species, namely *Grewia optiva*, *Morus alba*, *Bauhinia variegata*, *Robinia pseudoacacia*, *Melia azedarach*, *Dalbergia sissoo*, *Toona ciliata*, *Celtis australis*, *Gmelina arborea*, *Sapindus mukurosii* and *Albizia stipulata* was done in the arboretum at 3 × 3 m spacing, with 20 trees of each species, during January 1988 and allowed to grow under subtropical to sub-temperate climate. Observations with regard to leaf emergence and flower initiation commenced from January and continued till leaf abscission. The time taken from leaf emergence to leaf maturation was taken for individual tree species. Observation of flower initiation was recorded for each species. Visual observations for yellowing of the leaf (senescence) were made at 15 days interval. The tree species were also examined for variation in interspecific growth period. This important parameter was estimated on the basis of time taken from leaf emergence to senescence phase and expressed in days. These observations were made in 1999 and again in 2006 from January to December at 15 days interval. The trees were 18-year-old at the time of observation. Data for climate indicators such as maximum and minimum monthly temperatures and annual rainfall for eight years (1999–2006) were collected. The monthly temperatures and rainfall data were obtained from the Soil Science Department. Results are the comparison of phenological status of tree species in 1999 and 2006 and impact of climate change on phenophases in eight years.

Monthly as well as annual variation in temperature and rainfall was recorded during the entire period of experimentation, i.e. between 1999 and 2006. The differences in average annual temperature are shown in Figure 1. Data reveal increasing trend in temperature during eight years (1999–2006); for example, average annual temperature during 1999 was 23.4°C, which increased to 27.1°C by 2006. This increase in average temperature (3.7°C) in just eight years at the experimental site is substantial. Upward trend in temperature was evident during the entire experimental period (1999–2006), except that the average annual temperature in 2005 was lower in comparison to 2004 (Figure 1).

It was also thought essential to closely observe minute differences in monthly maximum temperatures recorded in 1999 and again during 2006 (Figure 2). Interesting results were obtained. The monthly temperature increase in 2006 compared to 1999 varied between 0.5°C and 8.1°C. Maximum increase of 8.1°C was recorded during February, followed by 7.6°C in September (Figure 2). January experienced increase of 3.1°C, whereas temperature in-

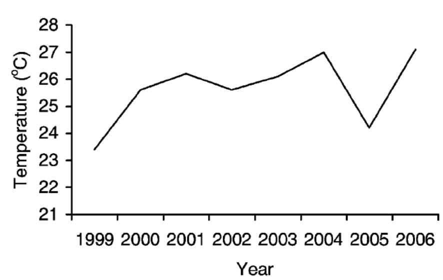

Figure 1. Variation in average temperature during the period 1999–2006.

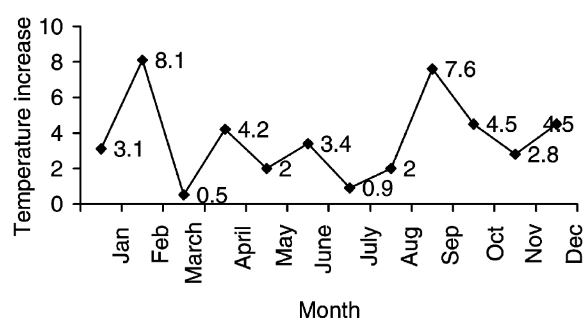

Figure 2. Monthly increase in average temperature (°C) in eight years (1999–2006).

crease during December was 4.5°C. Minimum increase in temperature (0.5°C) was observed during March, followed by 0.9°C in July. Variation (significant increase) in temperature in 2006 in comparison to 1999 is a reflection of fast-changing climate.

The monthly differences in average maximum and minimum temperatures are shown in Figure 3. It is clear from Figure 3 that significant differences existed in average maximum temperature between the two experimental years (1999 and 2006). The average maximum monthly temperature was significantly higher during 2006 in comparison to 1999. The average monthly temperature in the former ranged between 20.6°C and 32.1°C, while the same in the latter varied between 17.2°C and 30.1°C (Figure 3 *a*). Maximum temperature was recorded in May during both 1999 and 2006, where values were 30.1°C and 32.1°C respectively (Figure 3 *a*). Observations made with regard to minimum average temperatures do not reveal much change in monthly temperature between 1999 and 2006. For example, the average minimum monthly temperature during 2006 varied from 3.4°C to 20.9°C and during 1999 from 3.5°C to 23.0°C (Figure 3 *b*). It is clear that minimum average monthly temperature did not undergo any substantial change in eight years between 1999 and 2006, except that June to September had comparatively (1.3–2.4°C) higher temperature during 1999. The minimum average monthly temperatures in the remaining months were almost equal (Figure 3 *b*). January and December were the coldest months, whereas May and June were the hottest.

The observed trend for annual rainfall between 1999 and 2006 was unexpected and of serious concern. An overall decline in annual rainfall of the region was observed from 1999 to 2006. The annual rainfall received during 1999 was 1213.9 mm, which followed a declining trend up to 2006, where rainfall was 969.4 mm. During the present study, the decrease of 244.5 mm in precipitation in eight years between 1999 and 2006 is alarming and a reflection of climate change. Annual rainfall during 2000 was comparatively more than the preceding year. Minimum annual rainfall (906.3 mm) was recorded during 2005 (Figure 4). It was observed that monthly rainfall did not undergo any substantial drift in eight years (Figure 5). Maximum rainfall was received during the rainy season from July to September during both 1999 and 2006; total rainfall in July during 1999 was 455.2 mm, which declined to 243.9 mm in 2006. In the remaining months, almost equal precipitation was received. Thus, it is clear that inspite of significant decline in annual rainfall during eight years, the general monthly rainfall distribution has remained unchanged (Figure 5).

All the 11 multipurpose tree species were studied for status of phenological phases during 2006 and compared with the status of phenophases of these tree species in 1999. Phenophases such as leaf emergence, flower initiation and growth period were chosen to indicate the impact of interannual climate variability on phenology in eight years.

Leaf emergence (budburst), an important phase indicative of initiation of vital physiological activities in trees,

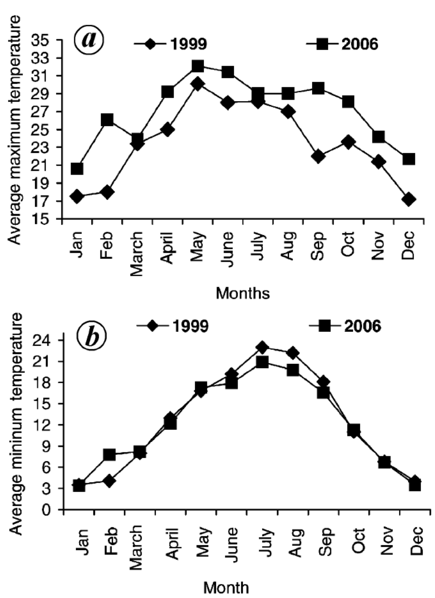

Figure 3. Monthly variation in average maximum temperature (***a***) and minimum average temperature (***b***) in 1999 and 2006.

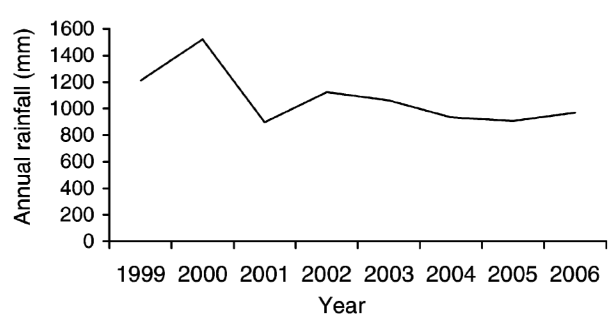

Figure 4. Pattern of annual rainfall during the period 1999–2006.

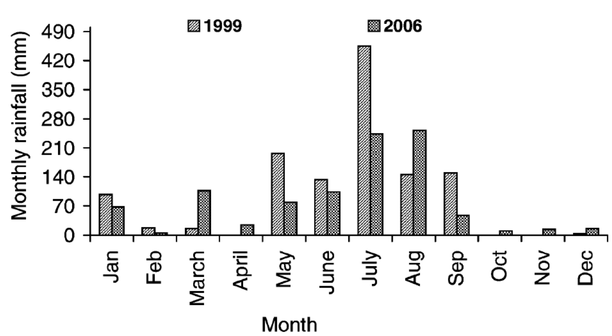

Figure 5. Monthly rainfall during 1999 and 2006.

advanced in all the tree species in eight years. Intergeneric variation was significant. Leaf emergence phase advanced ranging from 5 to 40 days in different species. This is a significant shift in the phenophase of tree species. The leaf emergence phase advanced by 5 days in *M. alba* and *A. stipulata*, whereas maximum advancement by 40 days was registered for *M. azedarach*. *D. sissoo*, *B. variegata*, *T. ciliata* and *S. mukurosii* advanced their leaf emergence phase by 34, 31, 25 and 25 days respectively, in eight years (Figure 6). The leaf emergence phase in the remaining tree species advanced by 15–22 days. This significant shift in leaf emergence phase of tree species is bound to have substantial influence on growth pattern/magnitude of these tree species. Earliness in leaf initiation will prolong total growth duration of the tree species, which is desirable and will benefit them.

Flower initiation is another important phenophase, which is the result of cumulative reflection of all the vital physiological processes in any individual tree. It was found during the present study that climate change significantly advanced the flower initiation phase. The flower initiation phase advanced by 40 days in *M. alba*, followed by *M. azedarach*, *D. sissoo* and *T. ciliata* where, the flower initiation phase advanced by 35 days. In *G. optiva*, *B. variegata*, *R. pseudoacacia*, *C. australis* and *A. stipulata*, the flower initiation phase advanced by 10–27 days (Figure 6). Flower initiation did not occur in *G. arborea* and *S. mukurosii*. The tree species seem to respond to climate change by adjusting their phenophases. These adjustments have been experienced in just eight years.

The findings with regard to status of growth period of multipurpose tree species during 1999 and 2006 are expressed as histograms. One of the early conspicuous effects of climate change during this study appears to prolong the growth period of the 11 multipurpose tree species tested within eight years. Compared to growth period of these tree species in 1999, where values varied between 116 and 275 days, the same ranged between 161 and 314 days during 2006. A significant increase in growth period was recorded in 2006. The growth period prolonged by 31–46 days in different species in eight years. This is a significant shift in growth behaviour of tree species. The maximum growth period of 314 days was observed for *C. australis*, whereas the minimum (161 days) was in *M. azedarach*. Growth period in *G. arborea* and *R. pseudoacacia* enhanced by 46 days, followed by 45 days in *T. ciliata* and *M. azedarach*. The remaining tree species shifted their growth period ranging from 31 to 41 days in eight years. There was no change in the growth period of *A. stipulata* during eight years (Figure 7).

The findings of this study seem to be of great relevance in the present scenario of fast-changing climate. The comparative study of variation in climate indicators and their possible impact on phenology of 11 multipurpose tree species within eight years is an eye-opener. A substantial shift in critical phenophases, including leaf emergence, flower initiation phase and growth period in a span of eight years seems to be associated with climate change and there is every reason to believe that the advancement in phenology of these tree species might be the result of climate change at the regional level. A perusal of data reveals that in all the 11 multipurpose tree species, leaf emergence phase, an important phase in the growth cycle of any individual tree, advanced significantly. This advancement in leaf emergence phase ranged between 5 and 40 days. Likewise, flower initiation phase advanced by 10–40 days in different tree species. The immediate effect of climate change on the growth period was also evident during this study, where increase in growth period ranging from no change to 46 days was noticed for

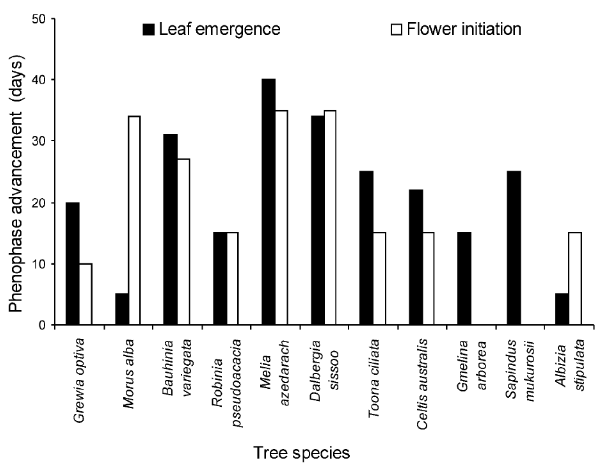

Figure 6. Advancement in leaf emergence (budburst) and flower initiation phase of tree species during eight years (1999 and 2006). $LSD_{0.05}$ to compare tree species for leaf emergence (5.0), flower initiation (3.0).

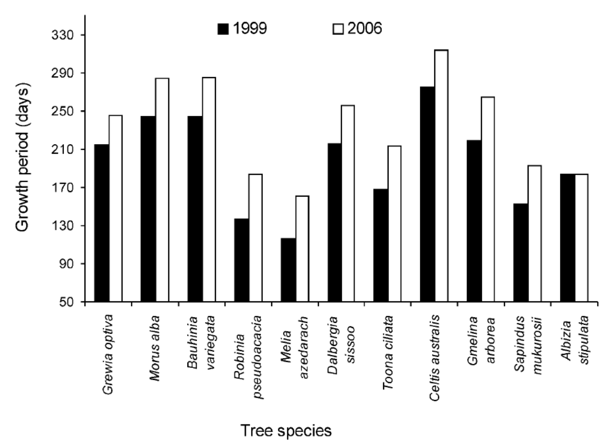

Figure 7. Variation in growth period of different tree species in eight years (1999–2006). $LSD_{0.05}$ to compare tree species for significance (9.0).

11 tree species. Nevertheless, the increase in average maximum temperature by 3.7°C within eight years is certainly a matter of great concern. On the contrary, a sharp decline in annual rainfall from 1213.9 mm during 1999 to 969.4 mm in 2006 is also not a good signal. In case this trend continues in the time to come, which seems to be a near probability in the context of global/regional warming, it may further worsen the situation. It is not clear how the increase in average temperature will benefit, especially the tree species, but the earliest effect of this climate indicator during the present study seems to advance important phenophases of trees, including enhancement in the general growth period. This situation practically should improve the performance and biomass production ability of tree species, at least in the temperate region. However, the decline in annual precipitation year after year will jeopardize vital physiological processes associated with the performance of individual tree species, possibly by affecting availability of moisture at different phenophases[13–15]. The impact of climate change on growth (e.g. height, diameter, biomass, leaf area index) and physiology of these 11 species is being studied. However, the intergeneric differences in growth behaviour and ecophysiological characteristics of these tree species have been studied earlier[13]. Differences in growth parameters like height, diameter at breast height, canopy management and leaf area index have been reported in our earlier study[13]. In addition, diurnal variation in physiological attributes like photosynthetic rate, amount of water transpired and xylem water potential of these tree species have also been reported earlier[16]. The imminent effect of climate change on phenology of these species is evident from the present data but how far the growth ability, pace of physiological processes and carbon sequestration potential of these 11 tree species have been affected by the change in climate during eight (1999–2006) years, is a topic of further investigation. Several workers in the western countries have indicated changed growth behaviour and phenology of many perennials[6,7,12,16–25]. In addition, the recent report of the IPCC[9] has given overview of global warming on flora and fauna. The report has clearly predicted the increase in temperature and CO_2 and the necessity for undertaking immediate steps, especially for CO_2 mitigation. During the present study we observed significant increase in temperature during January and February above normal, but a drop in temperature during March. This change adversely affects stone fruits in temperate regions[26]. Temperature increase advances flowering in fruits like apricot, plum and peach; the drop in temperature during March adversely influences pollination[26]. This shift in the phenophases over the years is one of the reasons for substantial reduction in fruit yield[26]. The impact of climate change on apple farming is also evident. For example, the increase in temperature above normal has resulted in the shift in apple cultivation area beyond 5000 ft, since apple plants could not fulfil the chilling requirement, a prerequisite for satisfactory flowering[27]. Change in temperature is mainly responsible for shift in apple cultivation area above the elevation of 5000 ft. The result is that apple growers in the northwest to northeast Himalayan region have shifted to vegetable farming. This change has occurred during the last decade. This is one of the major impacts of climate change on Indian agriculture. The shift in the phenophases and total growth period of agricultural as well as forest crops is expected to entirely change the production targets. The germplasm of food crops and multipurpose tree species existing today may not survive and cope with the fast-changing climate in the near future. The decline in annual rainfall each year is a matter of concern. This is the right time that scientists undertake sincere efforts and adopt holistic future planning to conserve and/or develop genetically superior germplasm, which is drought-tolerant, capable of enhancing photosynthetic efficiency at elevated CO_2, has higher carbon sequestration potential and better water productivity and adaptability, inspite of adverse conditions. Climate variability at the regional rather than global level needs to be looked into more closely in order to precisely understand the impacts on agricultural, fruit and forest crops under Indian conditions. Strategies and methodologies need to be evolved, which pave the way for comprehensive understanding of all aspects of climate change and their repercussions on the production scenario.

On the basis of the present findings there are ample reasons to conclude that the advancement in phenological phases of the 11 multipurpose tree species tested, might be the result of interannual climate variability during eight years (1999–2006). The leaf emergence and flower initiation phases had advanced. The growth period of multipurpose tree species was prolonged by 31–46 days. An increase in average maximum temperature and decline in annual rainfall was evident. The shift in phenophases was significant.

1. Thakur, P. S. and Kaur, H., Phenology of twelve multipurpose agroforestry tree species. In *Higher Plants of Indian Sub-Continent*, 2000, vol. IX, pp. 207–215 (additional series of *Indian J. For.*, XI).
2. Murray, M. B., Cannel, M. G. R. and Smith, R. I., Date of budburst of fifteen tree species in Britain following climate warming. *J. Appl. Ecol.*, 1989, **26**, 693–700.
3. Vinaya, S. G. and Kumbhojkar, M. S., Phenology of deciduous ornamental trees from western Maharashtra. *Indian J. For.*, 1991, **14**, 181–189.
4. Negi, G. S., Phenology, leaf and twig growth pattern and leaf nitrogen dynamics of some multipurpose tree species of Himalaya: Implementations towards agroforestry practice. *J. Sustain. Agric.*, 1995, **6**, 43–60.
5. Le, T. T. and Lechowicz, M. J., The photosynthetic response of eight species of *Acer* to stimulated light regimes from the centre and edges of gaps. *Funct. Ecol.*, 1997, **11**, 16–23.
6. Linkosalo, T., Analysis of the spring phenology of boreal trees and its response to climate change. University of Helsinki De-

partment of Forest Ecology Publications 22, ISBN 951-45-9362-6, ISSN 1235-4449, 2000.
7. Thakur, P. S. and Kaur, H., Variation in photosynthesis, transpiration, water use efficiency, light transmission and leaf area index in multipurpose agroforestry tree species. *Indian J. Plant Physiol.*, 2001, **6**, 249–253.
8. Thakur, P. S. and Sood, R., Drought tolerance of multipurpose agroforestry tree species during first and second summer drought after transplanting. *Indian J. Plant Physiol.*, 2005, **10**, 32–40.
9. Intergovernmental Panel on Climate Change, Fourth Assessment Report (AR 4), Climate change 2007: Synthesis Report.
10. Keeling, C. D., Chin, J. F. S. and Whorf, T. P., Increased activity of northern vegetation inferred from atmospheric CO_2 measurements. *Nature*, 1996, **382**, 146–149.
11. Myneni, R. B., Keeling, C. D., Tucker, C. J., Asrar, G. and Nemani, R. R., Increased plant growth in the northern high latitudes from 1981 to 1991. *Nature*, 1997, **386**, 698–702.
12. Menzel, A. and Fabian, P., Growing season extended in Europe. *Nature*, 1999, **397**, 659.
13. Thakur, P. S., Kashyap, T. and Thakur, A. S., Effect of moisture stress conditioning on the performance and water relationship of *Grewia optiva* seedlings during water deficit. *Indian J. Plant Physiol.*, 1998, **3**, 152–155.
14. Thakur, P. S., Influence of paclobutrazol and moisture stress conditioning on drought susceptibility in *Robinia pseudoacacia* seedlings. *J. Trop. For. Sci.*, 2000, **12**, 493–502.
15. Sood, R. and Thakur, P. S., Responses of multipurpose tree species to two successive summer droughts after transplanting. *Indian For.*, 2006, **132**, 841–849.
16. Thakur, P. S. and Dutt, V., Ecophysiological characteristics of six broadleaved agroforestry tree species. *Indian J. For.*, 2003, **26**, 168–171.
17. Billington, H. L. and Pelham, J., Genetic variation in the date of budburst in Scottish birch populations: Implications for climate change. *Funct. Ecol.*, 1991, **5**, 403–409.
18. Hari, P. and Hakkinen, R., The utilization of old phenological time series of budburst to compare models describing annual cycle of plants. *Tree Physiol.*, 1991, **8**, 281–287.
19. Braathe, P., Birch dieback – The effects of artificial spring frost on budburst and foliage. *Norw. J. Agric. Sci.*, 1996, **10**, 1–6.
20. Haakkinen, R., Linkosalo, T. and Hari, P., Effects of dormancy and environmental factors on timing of bud burst in *Betula pendula*. *Tree Physiol.*, 1998, **18**, 707–712.
21. Hanninen, H., Effects of climate change on trees from cool and temperate regions: An ecophysiological approach to modeling of budburst phenology. *Can. J. Bot.*, 1995, **73**, 183–199.
22. Kramer, K., Phenotipic plasticity of the phenology of seven European tree species in relation to climate warming. *Plant Cell Environ.*, 1995, **18**, 93–104.
23. Leinonen, I., Dependence of dormancy release on temperature in different origins of *Pinus sylvestris* and *Betula pendula* seedlings. *Scand. J. For. Res.*, 1996, **11**, 122–128.
24. Repo, T., Hanninen, H. and Kellomaki, S., The effects of long-term elevation of air temperature and CO_2 on the frost hardiness of Scots pine. *Plant Cell Environ.*, 1996, **19**, 209–216.
25. Monica, K. M. and Bhatnagar, A. K., Phenology and climate change. *Curr. Sci.*, 2005, **89**, 243–244.
26. Seventh International Symposium on Temperate Zone Fruits in the Tropics and Subtropics. Proceeding in Acta Horticulture (ISHS), 2004, **662**.
27. Jindal, K. K., Gautam, D. R. and Chauhan, A., Sustainable apple farming in north-east Himalayas under changing environment. In Second International Congress of Plant Physiology on Sustainable Plant Productivity under Changing Environment, 2003, vol. S 10-04, p. 432.

Received 11 June 2007; revised accepted 19 February 2008

RAPD analysis of soil microbial diversity in western Rajasthan

Nimisha Sharma, Y. Sudarsan*, R. Sharma and Govind Singh

Plant Biotechnology Centre, Rajasthan Agricultural University, Bikaner 334 006, India

RAPD analysis of DNA isolated from soils under Ker and associated open areas of Bikaner, Kodamdesar and Nagaur regions of western Rajasthan was carried out using six primers to find out the effect of Ker (*Capparis deciduas*) plants on microbial diversity. The average Jacard's coefficient similarity within Ker samples was less (0.250) than that within adjoining open area (0.337), indicating that the soil under Ker supports more diverse microbes compared to the open areas. Comparatively higher fertility status in terms of NPK and C content under Ker plants was envisaged to support more diverse types of microbes. The soils from the three locations were quite uniform both under Ker (94.53%) and in open area (94.76%).

Keywords: Fertility status, microbial diversity, RAPD analysis, soil.

SOIL microbial diversity is an important index of agricultural productivity[1–3]. Both the plant and soil types influence the microbial diversity of the rhizosphere[4,5]. Interaction of plants and microorganisms is a result of co-evolution and their balance is important for sustainable agriculture. The influence of perennials in microbial diversity is expected to be more pronounced in harsh climates of the desert. Such studies are scanty for the Thar Desert and most of them pertain to cultivable types, which represent only 1% of the total microbial diversity in the soil and hence, fail to envisage the entire population. DNA markers, including the RAPDs produced by PCR can be used for the characterization of microorganisms and detection of microbial diversity[6–12] in metagenome, without the need for culturing the same. The present investigation was thus carried out to study microbial diversity under the soils of Ker (*Capparis deciduas*) plant and adjoining open areas at three locations in the hot, arid Thar Desert, Rajasthan. The influence of Ker on fertility status of the soil was also estimated to associate microbial diversity with fertility status of the soils.

Soil samples were collected during June 2006 under Ker and open areas of Bikaner (BKN), Kodamdesar (KODM) and Nagaur (NGR), that have similar soils and vegetation. The samples from Bikaner represented the area that was under cultivation once (about 10 years ago), while the others were from uncultivated fallow barren lands. Cultivated land was included to find out if certain

*For correspondence. (e-mail: yemmanur_sudarsan@yahoo.co.in)