Urbanization: A potential factor in temperature estimates for crop breeding programs at international agricultural research institutes in the tropics

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Citation: Keatinge JDH, Ledesma D, Hughes Jd'A and Keatinge FJD. 2013. Urbanization: A potential factor in temperature estimates for crop breeding programs at international agricultural research institutes in the tropics. Journal of SAT Agricultural Research 11.

Introduction

This paper evaluates whether projections of the changes in annual average air temperature might be influenced by rapid urbanization occurring in areas surrounding the headquarters of several international agricultural research centers. This may make their meteorological data sets less representative of the rural environments being targeted by their plant breeding programs. Literature is then reviewed to determine whether biases in the estimates of warming may or may not have occurred. We suggest what the implications for breeding programs might be, given specific temperature projections and their potential validity in the face of urban development at several of the key international agricultural research institutes.

Review of literature

Given the likely substantive differences in thermal bulk properties and albedo (Peña 2009) between city construction materials and the vegetation and soils of the rural environment, it is unsurprising that differences in both day and night air temperatures have been observed by meteorologists between the city and the countryside for more than a hundred years. However, the technical measurements may have been questionable until Chandler (1962) clearly demonstrated that London had a specific urban climate distinct from its surrounding rural areas. This conclusion was also supported after an analysis of temperature data from a smaller city, Barcelona (Moreno-Garcia 1994).

Interest in this subject has been further stimulated by more recent issues associated with global warming and the work of Oke (1973, 1982), who attempted to quantify and explain the relative size of the heat island surrounding inner cities. Karl and Jones (1989) suggested that this effect would amend longer term air temperature trends, particularly in cities with large populations. Camilloni and Barros (1997) concluded that, as a result of the heat island effect, inter-annual variability of air temperature is often higher in rural environments compared to cities. Yet Peña's (2009) study of Santiago, Chile noted that the relative aridity of the rural environment may be an important factor in determining whether a city actually becomes either a heat island or a cool island.

The Intergovernmental Panel on Climate Change (IPCC) (Folland et al. 2001) acknowledges the likelihood of urban heat islands being real. However, the IPCC suggests that the difference when expressed over large areas would be small, and would probably not be a potent influence on current increasing temperature trends. Such a view is supported by Parker (2006), but the data presented for the Toronto area in Canada (Mohsin and Gough 2010) suggest otherwise. Mohsin and Gough (2010) report a significant linear trend in annual mean air temperature for urban stations, but this trend contrasts with rural counterpart locations in Ontario where the effects were not significant when assessed over the period 1878–1978.

In a study on vegetable growth, particularly the Brassicaceae, in rural Ontario, McKeown et al. (2006) and Warland et al. (2006) report that there was likely to have been significant warming post-1980 compared with the period 1955–1975, which was seen to have been more beneficial for the production of cool season vegetables. This is also somewhat reflected by the data for Vineland, Ontario (in a rural location but close to Toronto) which indicates slight but significant warming in the period 1975–2011, but not significant when considered over the longer period from 1926 to 2011 (Keatinge et al. 2012).

Materials and methods

This work is based on data recorded at international agricultural research centers across the globe, which were deliberately selected to avoid urban heat island effects to the maximum extent possible (Keatinge et al. 2012). The temperature record from each station was assessed for a consistent time period (from 1975 to 2011, where possible). Trends in expected temperature changes are discussed in the context of their general accord with the IPCC predictions. These were produced from complex models using multiple data sets and which incorporate data from urban, airport and rural meteorological stations. In such models, historical temperature records are frequently homogenized by combining records from urban and surrounding rural locations—for example, as used by Kuglitsch et al. (2009) for a study in the greater Mediterranean region. However, in this study we have deliberately sought to avoid mixing records, thus retaining the site-specificity of the data employed for trend estimation.

Annual average maximum and minimum air temperatures were calculated from monthly data recorded at seven agricultural research institutes. These locations were purposively selected to reduce bias in warming trends associated with large urban centers and airports, at which most major meteorological recording stations are now situated. Simple linear regression was used to predict the likely trends in average annual air temperature (Keatinge et al. 2012). Selected results are provided in this paper (Figs. 1 to 7).

Findings and interpretation

The IPCC (Folland et al. 2001, Parry et al. 2007) indicate that global increases in surface air temperature since the late 19th century are today between 0.4 and 0.8°C. Moreover, they state that it is likely that the 1990s was the warmest decade in the last 100 years, with most of the warming over the century occurring in two periods from 1910 to 1945 and since 1976. In support of this observation, successive periods of warming (1900–1940), cooling (1940–1965) and warming again (1965–2000) were suggested for USA by Hansen et al. (2001). Warming appears to have been greater over the land than over the oceans and it has been most prominent during the winter periods in the northern hemisphere outside of the tropical regions (Folland et al. 2001). For example, using data averaged over all Canadian provinces, Environment Canada (2012) has shown a projected increase of 3.2°C in annual average winter air temperatures for the period 1948–2012.

Peterson et al. (1999) compared a very large sample of specifically rural stations (2,290 stations) over the period 1880–1998 with a global data set encompassing more than 7000 stations. They found the average temperature increase for rural stations was 0.7°C/100 years, similar to the rate projected for the larger data set (0.65°C).

In contrast, substantive variation was evident between the sites reported by Keatinge et al. (2012) worldwide over the generally shorter, and more modern, reference period (1975–2011) than when compared to Folland et al. (2001) and Peterson et al. (1999). Such variation was clearly apparent in the trends at international agricultural research centers based in the tropics, including AVRDC (The World Vegetable Center), CIAT (International Center for Tropical Agriculture), CIMMYT (International Wheat and Maize Improvement Center), ICARDA (International Center for Agricultural Research in the Dry Areas), ICRISAT (International Crops Research Institute for the Semi-Arid Tropics), IITA (International Institute of Tropical Agriculture) and IRRI (International Rice Research Institute).

Smith et al. (2005) note that after 1970 there has been a period of large positive change in global average air temperature. In agreement with this assertion Keatinge et al. (2012) indicate that at some locations, rapid increases in air temperature are projected; for example, at sites in East Asia, such as the headquarters of AVRDC in Shanhua, Taiwan, which showed a rate of increase of 4.3°C/100 years in the period 1975–2011 (Fig. 1). In general, most sites worldwide showed some measure of warming, including CIAT (Palmira, Colombia, Fig. 2), CIMMYT (El Bataan, Mexico, Fig. 3), ICARDA (Tel Hadya, Syria, Fig. 4) and IRRI (Los Baños, Philippines, Fig. 5). Yet at a significant minority of other international agricultural research centers such as IITA (Ibadan, Nigeria, Fig. 6) and ICRISAT (Patancheru, India, Fig. 7) very little, if any, change was evident. In the cases of CIAT, ICARDA and IRRI (Figs. 2, 4 and 5), the surrounding fetch for their meteorological stations is generally large and rural. In contrast, IITA and ICRISAT each have at least 1000 ha of surrounding agricultural land on their farms, which should have minimized the potential urban influence; yet both centers are now being engulfed by the very large cities of Ibadan and Hyderabad, respectively (Figs. 6 and 7). Similarly, AVRDC's headquarters at Shanhua, Taiwan was completely rural in 1973, but over the last decade the surrounding area has experienced rapid urban development. This has come from the creation of a very large 'science park' for manufacturing and research, which has led to the expansion of housing and commerce

(Fig. 1). This issue is not restricted only to the headquarters locations of the international agricultural research centers in question as CIMMYT's breeding station at Toluca, Mexico has now essentially become part of the rapidly expanding Toluca city. Nevertheless, most centers also have other breeding locations in much more rural settings which are likely to be less affected by heat island influences.

Likely climate change and implications for plant breeding at international agricultural research centers

The implications of such variability in air temperature for plant breeding are profound, given existing opportunities to effectively exploit the range of genetic diversity available in climatically uncertain environments. The effects on vegetable horticulture have been comprehensively discussed by Keatinge et al. (2012) and more generally for a fuller range of climate change issues by Peet and Wolfe (2000).

In a groundbreaking paper, Peng et al. (2004) indicated that quite small increases in air temperature at IRRI, particularly night temperatures, may have had substantive effects on rice grain yields—a 10% decline in production for each 1°C increase in the dry growing season air temperature. At ICARDA, Ceccarrelli et al. (2010) recognized that warming temperatures would affect the headquarters barley breeding program, but were confident that the existing variation in barley germplasm would allow selection of material that could more effectively exploit the likely changing conditions.

At ICRISAT headquarters location at Patancheru, Kesava Rao and Wani (2011) examined predicted evapotranspiration from the high quality meteorological data set that has been collected at the institute since 1975. They concluded, somewhat paradoxically, that increasing day temperature conditions seemed to be associated with decreasing evapotranspiration rates. They indicated that the contribution of the energy balance term to the total

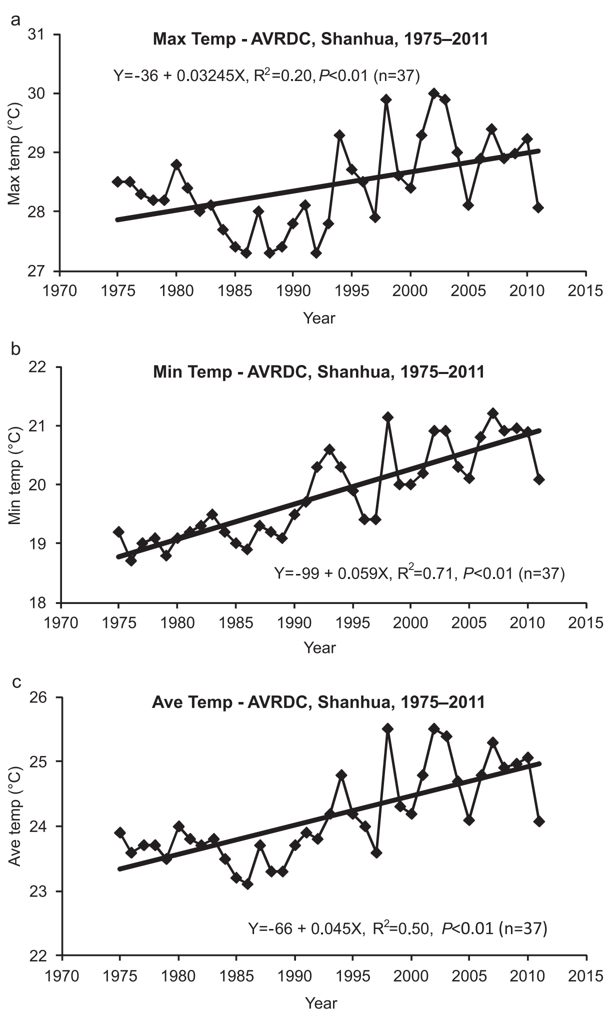

Figure 1. Annual air temperatures at AVRDC, Shanhua, Taiwan, 1975–2011: (a) maximum, (b) minimum and (c) average.

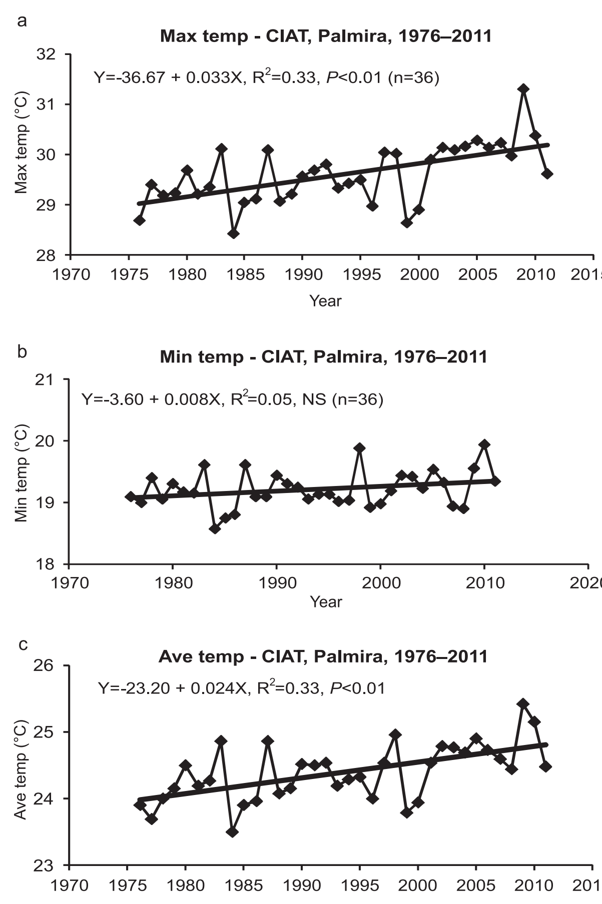

Figure 2. Annual air temperatures at CIAT, Palmira, 1976–2011: (a) maximum, (b) minimum and (c) average.

evapotranspiration had shown an increasing trend whilst the aerodynamic term had a decreasing trend. Wind speed had also shown a strongly negative trend. This was considered to be the likely explanation for the steep fall in evapotranspiration.

However, as indicated by Keatinge et al. (2012), ICRISAT's average air temperature record is composed of a marginally significant increasing trend in maximum air temperature, which is coupled with a significant decrease in minimum air temperature. These effects cancel each other out, so that when the data sets are combined in the calculation of annual average mean air temperature they result in the prediction of no temperature change for this location (Fig. 7). It should also be noted that the contrasting trends in maximum and minimum air temperatures result in a very low R^2 for average temperature which may therefore influence the robustness of future long-term temperature projections (Keatinge et al. 2012).

Cooper et al. (2009) argued that ICRISAT breeders at Patancheru may need to employ longer duration maturity types in their breeding programs rather than existing material. In a warming world, such material would have reduced maturity periods, which would then fit into the existing growing season. They argue that relying on current germplasm would risk very early forced maturity and thus bring about a substantive cut in crop yield potential. Vadez et al. (2011) also made an assumption that a 2–4°C increase in temperature will occur at ICRISAT headquarters in the near future; by doing so they are seeking to identify heat- and drought-tolerant germplasm. However, given that night temperatures are falling faster than day temperatures are increasing, with the overall effect being no change, this approach may not be useful for finding climate-resilient germplasm.

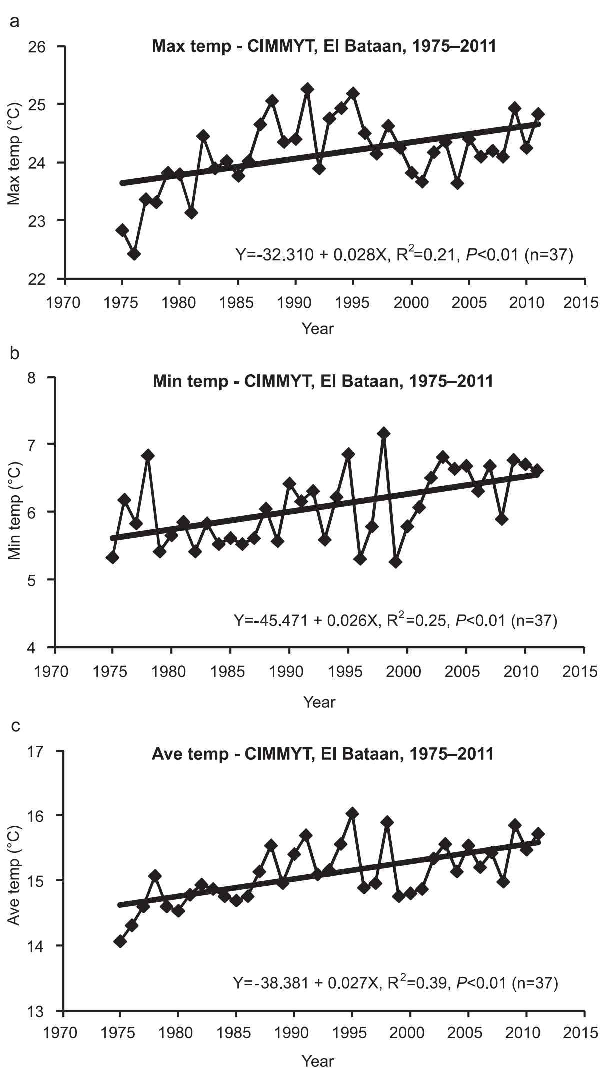

Figure 3. Annual air temperatures at CIMMYT, El Bataan, 1975–2011: (a) maximum, (b) minimum and (c) average.

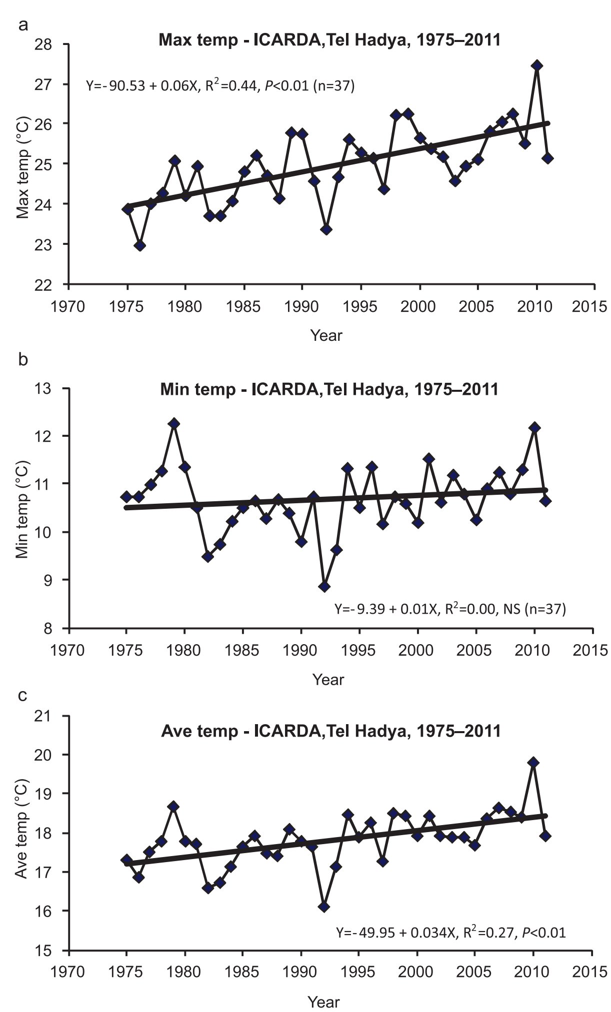

Figure 4. Annual air temperatures at ICARDA, Tel Hadya, 1975–2011: (a) maximum, (b) minimum and (c) average.

Jarvis et al. (2012) report that a warming world could result in potential reductions in the productivity of key African staple crops such as banana (*Musa* spp.), beans (*Phaseolus vulgaris*), maize (*Zea mays*), potato (*Solanum tuberosum*) and sorghum, yet they also postulate that cassava (*Manihot esculenta*) might be sufficiently flexible to adapt to changing conditions and expand its growing area. They also warn that higher temperatures, as projected for 2030, appear to play a less critical role in the potential expansion of cassava area in Africa than the comparatively low temperatures experienced in mid-elevation regions. They suggest therefore some additional cold tolerance may be required to prevent cessation of growth at 17°C if the cassava area is to expand substantially to replace other staple crops.

For IITA breeders operating principally at headquarters, the issue of breeding for temperature change poses something of a dilemma, given that at IITA, Ibadan no substantive temperature increase was experienced in the period 1975–2011. How long might this linear projection last? How might it be influenced by the rapid urbanization being experienced in Ibadan?

Although the answers to these questions are unknown, a prudent course of action for IITA, ICRISAT and AVRDC breeders would be to factor in the potential for a further rise in temperature in their home environment. These institutions should also collect sufficient and appropriate data to discern whether this is a "real" rise in overall temperature conditions, rather than one derived from the possible influence of albedo changes in the surrounding landscape as cities grow around the centers.

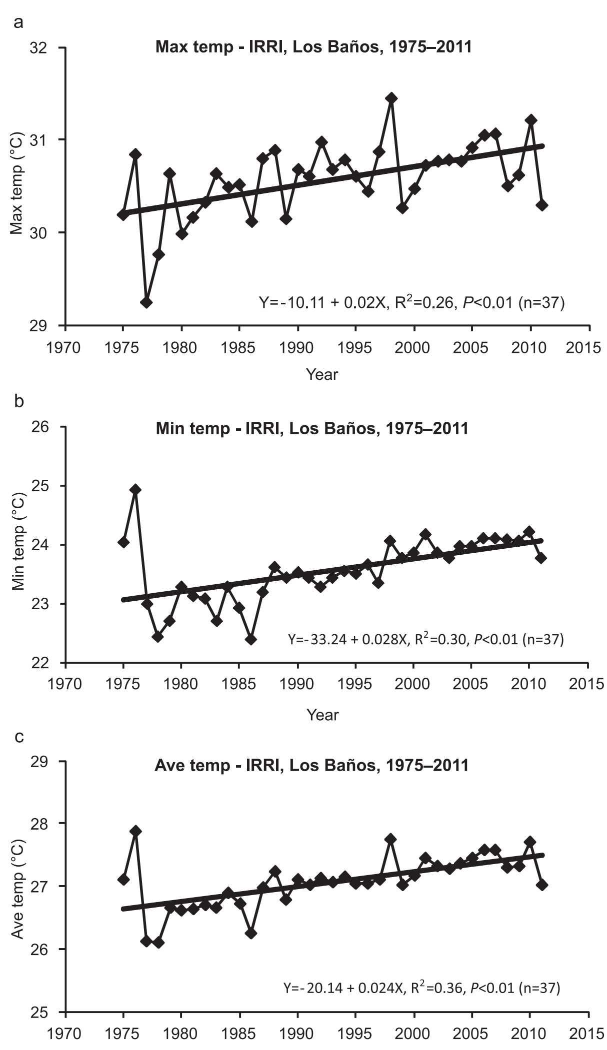

Figure 5. Annual air temperatures at IRRI, Los Baños, 1975–2011: (a) maximum, (b) minimum and (c) average.

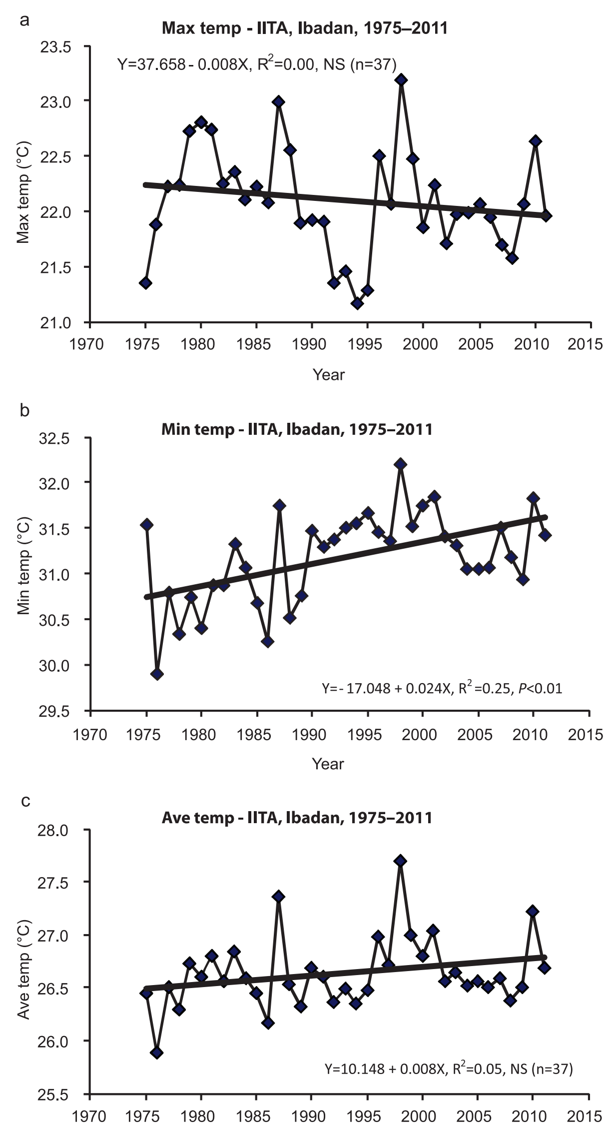

Figure 6. Annual air temperatures at IITA, Ibadan, 1975–2011: (a) maximum, (b) minimum and (c) average.

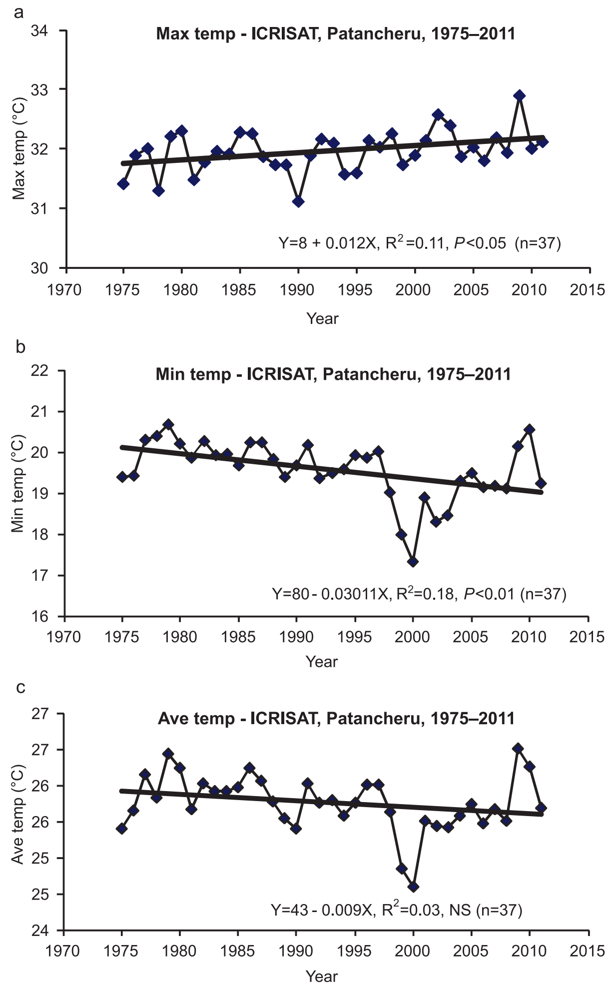

Figure 7. Annual air temperatures at ICRISAT, Patancheru, 1975–2011: (a) maximum, (b) minimum and (c) average.

Conclusions

To estimate the current rate of change in air temperature at a specific location, considerable care must be taken to select an appropriate climatic record of consistent length on which to base a reliable prediction of future events. For agricultural research with multiple field trials, use of meteorological station records (from locations in a comparable rural environment) that are as close to the experimental locations as possible is highly desirable, as local geographic variation in long-term effects seems to be distinctive (Keatinge et al. 2012).

Scientists whose work is principally dependent on meteorological records collected at locations threatened by urbanization now need to seriously consider whether their experimental sites are appropriate. CIMMYT's breeding station at Toluca, Mexico is now surrounded by housing areas as the city expands (Kai Sonder, personal communication, 2/6/2012). This may have outcomes which compromise the original value for breeding of the location. New, specifically rural locations for such research may now have become a necessity.

Whether meteorological data records from urban and rural stations can be combined without introducing substantive errors into analysis of air temperature changes seems to be an uncertain finding. Given the literature review in this paper sufficient doubt remains for caution to be applied if such combinations are being considered. This is particularly the case in support of issues such as plant breeding. Many important meteorological recording stations worldwide are located at airports that historically started as grass fields and are now mega-areas of high-albedo concrete runways and buildings. Where a station started as rural and then has been rapidly urbanized within the historical period of the analysis, considerable care needs be taken to avoid potential error from urban temperature island effects resulting in the selection of plant varieties somewhat inappropriate for their target rural farmland.

Further research to differentiate between overall global warming due to climate change and more microclimatic changes in temperature and other meteorological variables due to a city or town growing is now required. Very careful site selection of existing records will be needed to achieve this goal.

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