harvest date increased (Table 5). The increase in air temperature from April to May likely contributed to the enhancement of these factors, especially since the air temperature significantly influenced bedding temperature, and the optimum soil temperature for numerous sweetpotato cultivars is about 86 °F (30 °C) (Nakatani, 1992). In our study, May temperatures were closer to this optimum than April temperatures.

The acceptance of a cultivar by the consumer and subsequent local production of this cultivar by the sweetpotato growers, often determines the amount grown in an area. Of the cultivars tested, 'Potojam' produced more slips both years (Table 5). 'Potojam' also produced the highest number of slips at the early harvest date (data not shown). However, of the cultivars tested, it is the least accepted among consumers in Missouri.

Based on these results, Pro-mix BX is the most effective bed cover in producing early, good quality sweetpotato slips. Slips from the sawdust-covered roots were similar in quality to those from Pro-mix. With the relatively high cost of Pro-mix BX and the abundance of sawdust, economic factors may dictate the use of sawdust as the bed cover for producing slips in early spring in order that sweetpotato be produced as a profitable alternative crop.

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An Updated Hardiness Zone Map for Dallas–Fort Worth, Texas

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ADDITIONAL INDEX WORDS. cold hardiness, microclimate, urban heat island

SUMMARY. The combination of concrete and asphalt surfaces, large buildings, lack of surface water, and anthropogenic heat inputs result in urban temperatures warmer than surrounding rural areas. This effect is often most pronounced with winter minimum temperatures and may cause changes in local plant hardiness zones. Local minimum temperatures were obtained for the years 1974–96 from the National Climatic Data Center and the Office of the State Climatologist of Texas for all recording stations within the Dallas–Fort Worth, Texas metropolitan area. Data were averaged and analyzed in two groups: 1974–86 and 1987–96. Contour maps were created using Surfer software. The 1974–86 local map had only one major difference from the 1990 USDA Plant Hardiness Zone map, which was the inclusion of 8a temperatures in more western portions of the metroplex. The inclusion of the years 1987–96 resulted in the westward expansion of 8a and a new 8b zone near downtown Dallas. These changes mimic the expansion of suburban development and increased urbanization over the last decade. We propose an updated plant hardiness zone map for this metropolitan area, which should more accurately reflect changes that have occurred since publication of the USDA Plant Hardiness Zone map.

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No environmental factor limits the distribution of plants more than low temperature (Salisbury and Ross, 1992). Gardeners acknowledge this through the use of hardiness zone maps. Several maps have been created and revised through the years, beginning with a map published by Rehder (1927), a subsequent map created by USDA (1972), and continuing through the most recent USDA map (USDA, 1990). The American Horticultural Society has recently published a Plant Heat Zone map to illustrate ranges of high temperatures across the U.S. (Cathey, 1998). These maps tend to effectively provide information on a continental scale, and many microclimatic discrepancies may occur (Harp, 2000; Wyman, 1940).

Urbanization can be a major cause of local climate change. The prevalence of building materials such as asphalt and concrete, along with the lack of surface moisture result in average annual temperatures 4 to 6 °F (2.2 to 3.3 °C) warmer than those in the surrounding countryside (Landsberg, 1981; Oke, 1987). This urban "heat island" effect persists during the winter months, and, for many cities, has the greatest intensity when concerning minimum temperatures (Landsberg, 1981).

The objective of this study was to determine if winter minimum temperature differences could be found in the urban Dallas/Fort Worth, Texas (DFW) metropolitan area, and if these differences were great enough to alter local hardiness zone designations.

Methods and materials

Annual minimum temperatures were obtained for the DFW metroplex (Table 1), including surrounding counties (Fig. 1), from the Office of the State Climatologist of Texas and from the National Climatic Data Center's (NCDC) on-line data access at <http://lwf.ncdc.noaa.gov/oa/ncdc.html> for the years 1974–96 (NCDC, 2002). Data

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Table 1. Mean annual minimum temperatures in °F [°C = 5/9 (°F – 32)] for Dallas/Fort Worth, Texas and surrounding recording stations, 1974–96. These means are obtained by averaging the lowest temperature recorded during a calendar year across all years included in the study. Stations presented had a minimum of 15 years of data during the study period.

Station	Year 1974–96	1974–86	1987–96	DT[z]
Bardwell Dam	11.9	11.7	12.2	0.5
Benbrook	11.0	12.4	9.6	2.8
Dallas Love	14.8	12.5	17.0	4.5
DFW Intl. Airport	13.4	11.6	15.2	3.6
Cleburne	12.3	10.5	14.1	3.6
Denton	11.9	9.8	14.0	4.2
Grapevine	11.1	10.8	11.4	0.6
Corsicana	13.8	12.2	15.4	3.2
Ferris	12.3	11.7	13.0	1.3
Kaufman	12.0	10.2	13.9	3.7
Waxahachie	12.5	11.1	13.9	2.8
Pilot Point	10.5	8.1	13.0	4.9
Weatherford	8.4	6.5	10.3	3.8
Average	11.9	10.7	13.3	2.6

[z]Difference in mean temperatures between the time periods, 1974–86 and 1987–96.

included 13 recording stations, all of which were present in the 1990 USDA map (Kramer and LaMarca, 1990). This dataset was divided into: 1974–86, which corresponds to the current USDA map; and the subsequent years, 1987–96. Data for each individual station were analyzed and those with fewer than 15 years of continuous data were excluded. This included the Burleson and Arlington, Texas recording stations, which, for the time period of interest, had accumulated only 6 and 3 years of data, respectively. Stations with micro-climatic anomalies were not included in this study. All temperature data was received and analyzed in Fahrenheit.

A base map was created using the U.S. Census Bureau (USCB) TIGER map system at <http://tiger.census.gov/cgi-bin/mapbrowse-tbl/> (USCB, 2002). This is an online mapping program that uses census and geographic data to create accurate local maps. To insure ease of use and accurate georeferencing we included county lines, and a latitude/longitude grid.

Contour lines were drawn using Surfer 6.0 (Golden Software, Inc. Golden, Colo.), a commercial contour mapping software. The grid was drawn using the krigging option. Krigging uses a series of equations to estimate the location of contour lines from control point values. Contour lines were drawn in increments of 2.5 °F (1.39 °C). Corners were created to correspond with the geographic coordinates of the base map. The final image was edited, including removal of extraneous lines, and converted into a form suitable for presentation.

Hardiness zones were designated using the same guidelines as the 1990 USDA map, modified only to increase precision at the local level. The a and b zones 5 °F (2.8 °C) were subdivided into 2.5 °F increments which were designated Xa_1 and Xa_2. The new designation for USDA Hardiness Zone 7 with temperatures between 0 and 10 °F would be as follows: $7a_1$ = 0 to 2.5 °F (–17.78 to –16.39 °C), $7a_2$ = 2.6 to 5 °F (–16.33 to –15.0 °C), $7b_1$ = 5.1 to 7.5 °F (–14.94 to –13.61 °C), and $7b_2$ = 7.6 to 10 °F (–13.56 to –12.22 °C).

Results and discussion

Minimum temperatures from 1987–96 in the DFW metroplex were an average 5 °F warmer than the previous 12 years (Table 1). It appears that temperature increases were the greatest in areas of substantial urbanization. The increases ranged from a low of 0.5 °F (–17.5 °C) in Benbrook in western Tarrant County, to a high of 4.2 and 4.9 °F (2.33 and 2.72 °C) in Denton County, which had a population growth of 52.3% between the years 1980 and 1990 (Forstall, 1995). Parker County, west of the metroplex, remained relatively static in terms of growth, with a 1980–90 population increase of less than 1%, maintained stable minimum temperatures (Forstall, 1995).

Figures 2 and 3 illustrate how temperatures have changed in the last 10 years. Minor differences exist between the 1990 USDA map (Fig. 2) and our interpretation (Fig. 3). This is not surprising in that the DFW map is relatively similar topographically and has many reliable recording stations. This prevents errors when building contour maps. However, the increased precision of our map allowed us to identify an $8a_2$ area in Dallas, illustrating a trend toward warmer urban temperatures in the Dallas area. The new map also includes an area of temperatures in Collin County that are cooler than suggested in the USDA map. This, again, is most likely related to the increased precision of the new map.

A comparison of Fig. 3 with Fig. 4 illustrates a warming of temperatures across the DFW metroplex in recent years. The most obvious changes include the presence of $8b_1$ zones near the downtown areas of Dallas and Fort Worth, and the expansion of 8a into almost all of Tarrant County.

Changes in the distribution of marginally cold hardy landscape plants reflect the warming trends indicated in

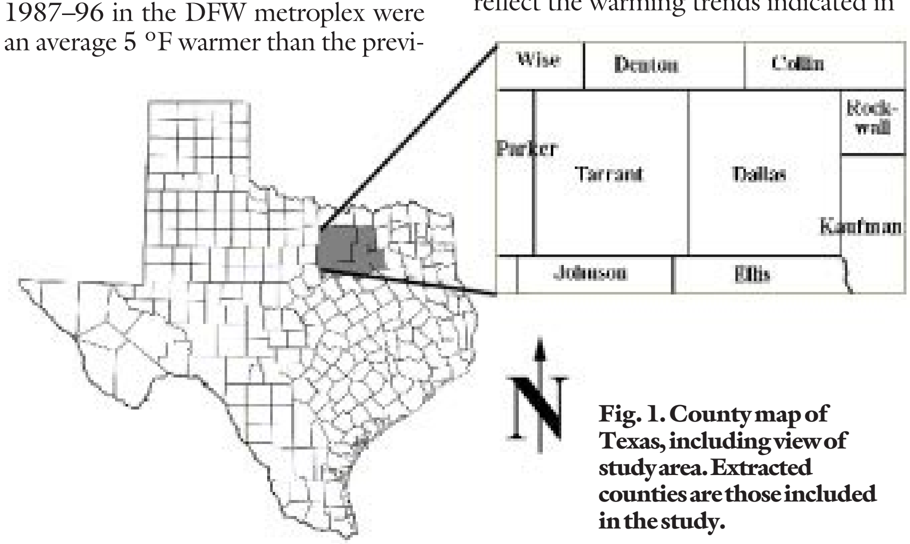

Fig. 1. County map of Texas, including view of study area. Extracted counties are those included in the study.

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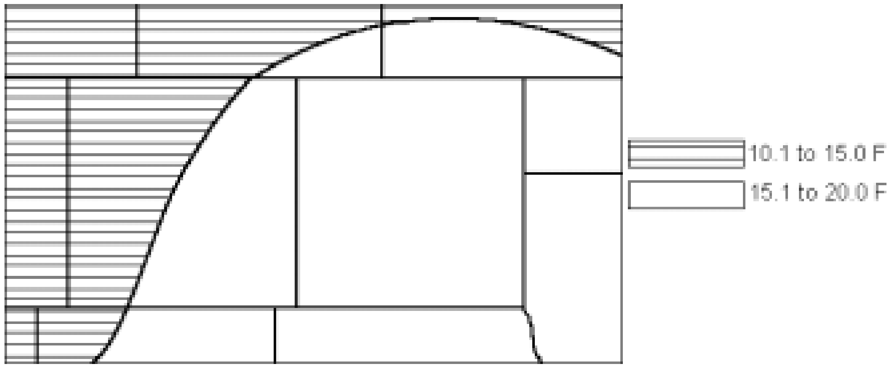

Fig. 2. USDA Hardiness Zone map for the Dallas–Fort Worth metroplex (USDA, 1990). Numbers indicate plant hardiness zone designation at in °F [°C = 5/9 (°F – 32)].

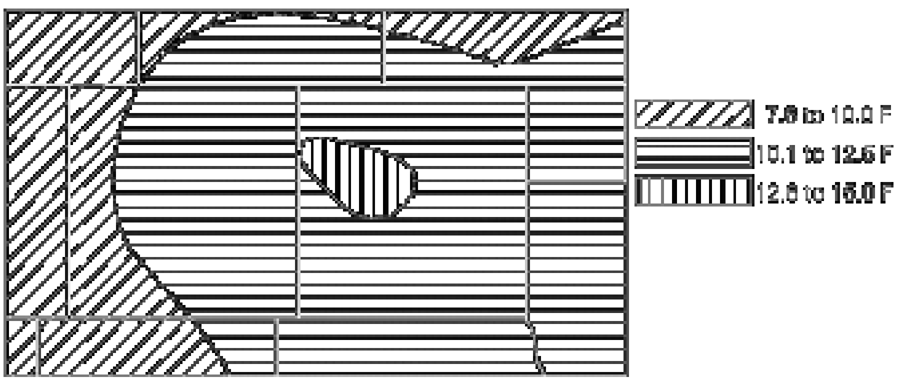

Fig. 3. Harp Hardiness Zone map for the Dallas–Fort Worth metroplex, 1974–86. Numbers indicate plant hardiness zone designation at °F [°C = 5/9 (°F – 32)].

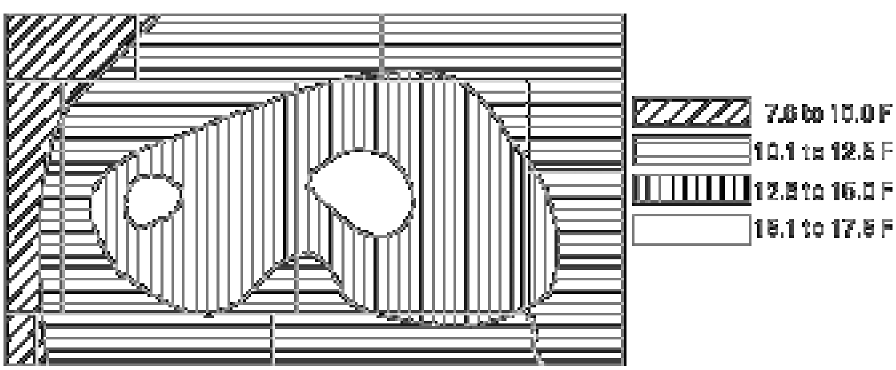

Fig. 4. Harp Hardiness Zone map for the Dallas–Fort Worth metroplex, 1974–96. Numbers indicate plant hardiness zone designation at °F [°C = 5/9 (°F – 32)].

Fig. 4. Sago palm (*Cycas revoluta*), windmill palm (*Trachycarpus fortunei*), fig ivy (*Ficus pumila*), and algerian Ivy (*Hedera canariensis*) are readily found in Highland Park and University Park, communities north of downtown Dallas. The Liberty Hyde Bailey Hortorium (1976) considers these plants to be tender, hardy only through zones 8b and 9. These species are rarely used in the Fort Worth area, and could not be found in the western and northern extremes of the DFW metroplex. All of the plants were verified by local gardeners to have been planted for at least 5 years with no cold injury more serious than minor tip burn. The survival of subtropical species for several years seems to be indicative of warm local and microclimatic temperatures.

Warmer urban temperatures occur in virtually every city. For many cities, this effect is most pronounced with minimum temperatures during the winter months (Landsberg, 1981). This can have a direct effect on landscape plants by decreasing the chance of low temperature damage and expanding the opportunities for a species' use in new areas (Harp, 2000; Landsberg, 1981).

As hardiness maps are revised, the use of local hardiness zone maps may provide the most accurate climatic information. Horticulturists can then predict the survival of individual species with more accuracy. To ensure the accuracy of hardiness zone maps, these should be revised on a regular basis. Further study is warranted to determine the most accurate length of time for predicting subsequent winter minimum temperatures.

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