12-1992

Performance of Landscape Plants from Yugoslavia in the North Central United States

Mark P. Widrlechner
United States Department of Agriculture, isumw@iastate.edu

Edward R. Hasselkus
University of Wisconsin-Madison

Dale E. Herman
North Dakota State University--Fargo

Jeffery K. Iles
Iowa State University, iles@iastate.edu

John C. Pair
Kansas State University

See next page for additional authors

Authors
Mark P. Widrlechner, Edward R. Hasselkus, Dale E. Herman, Jeffery K. Iles, John C. Pair, Ellen T. Paparozzi, Robert E. Schutzki, and David K. Wildung

Performance of Landscape Plants from Yugoslavia in the North Central United States[1]

Mark P. Widrlechner,[2] Edward R. Hasselkus,[3] Dale E. Herman,[4] Jeffery K. Iles,[5] John C. Pair,[6] Ellen T. Paparozzi,[7] Robert E. Schutzki,[8] and David K. Wildung[9]
North Central Regional Plant Introduction Station
Iowa State University
Ames, IA 50011

Abstract

From 1975 through 1979, 38 new, landscape plant introductions from Yugoslavia were distributed for testing in the NC-7 Regional Landscape Plant Trials. Twenty-seven of these introductions were evaluated for 10 years at seven or more sites, representing a broad range of environmental conditions in the north central United States. For these 27 introductions, first-year survival averaged 71%. Only four introductions had less than 50% first-year survival. Tenth-year survival varied widely among introductions and trial sites. Eight populations were adapted to most trial sites, ten populations were adapted to some sites, and nine populations were not adapted to any site. The most promising and broadly adapted introductions were *Viburnum opulus*, *Pinus sylvestris*, and *Pinus nigra*. Temperature and moisture data from Yugoslavia and from trial sites were used to examine relationships between plant adaptation and climate. Statistically significant, multiple-regression models were calculated that describe the functional relationships of low temperatures and moisture conditions at trial sites with adaptation. The models predict that these plants are best adapted to sites with winters milder than those typical in the north central United States and with precipitation in excess of potential evapotranspiration.

Index words: Plant evaluation, introduction, climate.

Species used in this study: Hedge Maple (*Acer campestre* L.); Italian Maple (*Acer opalus* Mill. subsp. *obtusatum* (Waldst. & Kit.) Gams); European Hornbeam (*Carpinus betulus* L.); European Euonymus (*Euonymus europaeus* L.); European Ash (*Fraxinus excelsior* L.); Flowering Ash (*Fraxinus ornus* L.); Common Juniper (*Juniperus communis* L.); Scotch Laburnum (*Laburnum alpinum* (Mill.) Bercht. & Presl); European Privet (*Ligustrum vulgare* L.); European Hophornbeam (*Ostrya carpinifolia* Scop.); Serbian Spruce (*Picea omorika* (Pančić) Purkyně); Swiss Mountain Pine (*Pinus mugo* Terra); Austrian Pine (*Pinus nigra* Arnold); Scotch Pine (*Pinus sylvestris* L.); Whitebeam Mountainash (*Sorbus aria* (L.) Crantz); European Cranberrybush Viburnum (*Viburnum opulus* L.).

Significance to the Nursery Industry

The climates and soils of the north central United States limit the variety of trees and shrubs that can be successfully produced and that are functional in the landscape. New plants from regions with climates similar to those in the north central region may serve to increase the diversity of species available to the trade, especially after adequate testing. This study, which evaluated new introductions from Yugoslavia, produced three findings of significance to the nursery industry.

First, eight of 27 populations tested performed well under a wide range of cultural and climatic conditions. These populations should be examined closely for future commercial production. Second, multiple-regression models were developed that relate commonly available moisture and temperature data to plant survival throughout the region. Finally, the results of these evaluations yielded criteria for identifying promising sites for future exploration and collection.

Introduction

From 1975 through 1979, the North Central Regional Plant Introduction Station, Ames, Iowa, distributed 38 new landscape plant introductions from Yugoslavia, as part of the NC-7 Regional Landscape Plant Trials, a long-term evaluation network conducted by cooperators at sites representing the climatic and edaphic variation of the north central United States (23). These introductions included a diverse selection of trees and shrubs collected from natural populations throughout much of Yugoslavia.

Cooperators were particularly interested in these collections for a number of reasons. Past experience with privet (*Ligustrum*) evaluations in the NC-7 Trials (6) indicated that Yugoslavia could be a valuable source of well-adapted new landscape plants. The privet best adapted to much of the north central region was a *L. vulgare* L. introduction from

[1]Received for publication April 18, 1992; in revised form July 20, 1992. Journal Paper No. J-14831 of the Iowa Agriculture and Home Economics Experiment Station, Ames, Iowa. Project No. 1018. The authors thank P.K. Bretting, R.E. Carlson, H.L. Flint, J.E. Klett, and A.M. Townsend for useful critiques of this report; L. Rajevski for providing seed samples from Yugoslavia; and A. Balak, G. Henricks, P.L. Koch, N. Rose, D. Tober, S. Zwinger, the Kansas Weather Data Library, and the High Plains Climate Center at the University of Nebraska-Lincoln for providing climate data.

[2]Horticulturist, USDA-Agricultural Research Service, Ames, IA 50011.

[3]Professor, Univ. of Wisconsin, Dept. of Horticulture, 1575 Linden Drive, Madison, WI 53706.

[4]Professor, North Dakota State Univ., Dept. of Horticulture & Forestry, Box 5658, Fargo, ND 58105.

[5]Predoctoral Extension Associate, Iowa State Univ., Dept. of Horticulture, Ames, IA 50011.

[6]Research Horticulturist, Kansas State Univ., Horticulture Research Center, 1901 East 95th St. South, Wichita, KS 67233.

[7]Associate Professor, Univ. of Nebraska, Dept. of Horticulture, 377 Plant Sciences Bldg., Lincoln, NE 68583.

[8]Assistant Professor, Michigan State Univ., Dept. of Horticulture, Plant & Soil Science Bldg., East Lansing, MI 48824.

[9]Professor, University of Minnesota, North Central Experiment Station, 1861 Highway 169 East, Grand Rapids, MN 55744.

Yugoslavia, which was released in 1965 by the United States Department of Agriculture and cooperating State Agricultural Experiment Stations as the cultivar 'Cheyenne'.

Yugoslavia and neighboring regions contain many endemic woody plants, such as *Forsythia europaea* Degen & Bald., *Petteria ramentacea* (Sieber) K. Presl, *Picea omorika* (Pančić) Purkyně, *Pinus heldreichii* Christ, and *Spiraea cana* Waldst. & Kit. (20), suggesting that the genetic diversity of woody plants could be higher there than in other parts of Europe with similar climates. In addition, Yugoslavia is located at the boundary of Mediterranean and Continental climates (8). Its location, along with its mountainous topography, produces meso- and microclimatic diversity. These factors all suggest that Yugoslavia could be a promising source of new landscape plants for the north central United States.

This study reports on the performance of diverse populations of trees and shrubs from Yugoslavia, in light of the natural history of the species tested and the environmental conditions at both collection and trial sites. These performance data may be useful in planning future plant explorations and in examining climatic limitations to plant adaptation in the north central region.

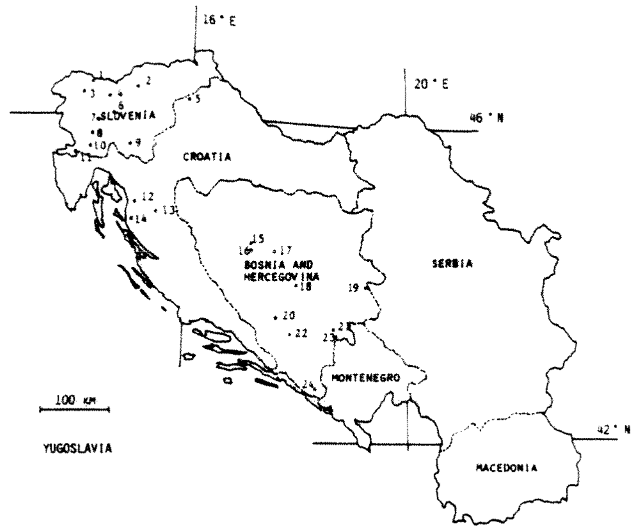

Fig. 1. Map of collection sites in Yugoslavia. Legend. See Table 1.

Materials and Methods

Twenty-seven seedling populations of trees and shrubs from Yugoslavia were included in this study, because they were thoroughly evaluated in at least seven trial sites. The species and collection site of each population are listed in Table 1, with collection sites mapped on Fig. 1. Populations were collected in two general regions: northwest Yugoslavia (Croatia and Slovenia) and south central Yugoslavia (Bosnia and Hercegovina). Seedlings were grown at the North Central Regional Plant Introduction Station and were distributed for evaluation at 41 sites. Cooperators at 14 sites (Fig. 2) reliably reported evaluation data for the duration of this study so only data from those sites are reported here.

Table 1. Yugoslavian plants evaluated and collection sites.

Taxon	PI number	Collection site,[z] province,[y] and elevation (in meters)	Map code (Fig. 1)
Acer campestre L.	399308	Vinac near Jajce, B, 670	16
Acer opalus Mill. subsp. *obtusatum* (Waldst. & Kit.) Gams	399315	near Kočevje, S, 600	9
Carpinus betulus L.	377783	Vrhovine near Perušić, C, 530	13
Euonymus europaeus L.	399360	near Travnik, B, 480	17
Fraxinus excelsior L.	377816	Kreševo near Fojnica, B, 800	18
Fraxinus excelsior L.	377817	Jajce, B, 400	15
Fraxinus excelsior L.	385251	Mt. Velež near Nevesinje, B, 650	22
Fraxinus ornus L.	385252	Zupci near Trebinje, B, 450	24
Juniperus communis L.	377822	Tjentište, B, 980	21
Laburnum alpinum (Mill.) Bercht. & Presl	377829	under Mt. Alančić peak, C, 950	14
Ligustrum vulgare L.	399377	near Vrhnika, S, 400	7
Ostrya carpinifolia Scop.	377841	Mt. Prenj, B, 620	20
Ostrya carpinifolia Scop.	377842	under Mt. Alančić peak, C, 950	14
Ostrya carpinifolia Scop.	377844	Mt. Stahinšćica near Krapina, C, 570	5
Ostrya carpinifolia Scop.	377845	near Vratnik passage, C, 610	12
Picea omorika (Pančić) Purkyně	399396	Mt. Babina Gora near Višegrad, B, 940	19
Pinus mugo Terra	377847	Mt. Maglić, B, 1240	23
Pinus mugo Terra	399398	Mt. Begunjščica, S, 700	1
Pinus nigra Arnold	399400	between Pivka & Hrastje, S, 500	8
Pinus nigra Arnold	399401	Črni Kal near Koper, S, 400	11
Pinus sylvestris L.	399402	between Pivka & Hrastje, S, 500	8
Pinus sylvestris L.	399403	Spodnji Brnik near Kranj, S, 400	4
Pinus sylvestris L.	399404	Mt. Kurescak near Ljubljana, S, 750	6
Sorbus aria (L.) Crantz	399409	Gorjuše near Bohinjska Bistrica, S, 1100	3
Viburnum opulus L.	399414	Brdo near Ljubljana, S, 320	6
Viburnum opulus L.	399415	near Mozirje, S, 350	2
Viburnum opulus L.	399416	Ribnica between Ilirska Bistrica & Gornje Vreme, S, 400	10

[z]Whenever possible, spellings for place names conform to the *Gazetteer of Yugoslavia* (7).

[y]Province abbreviations: B = Bosnia & Hercegovina, C = Croatia, and S = Slovenia.

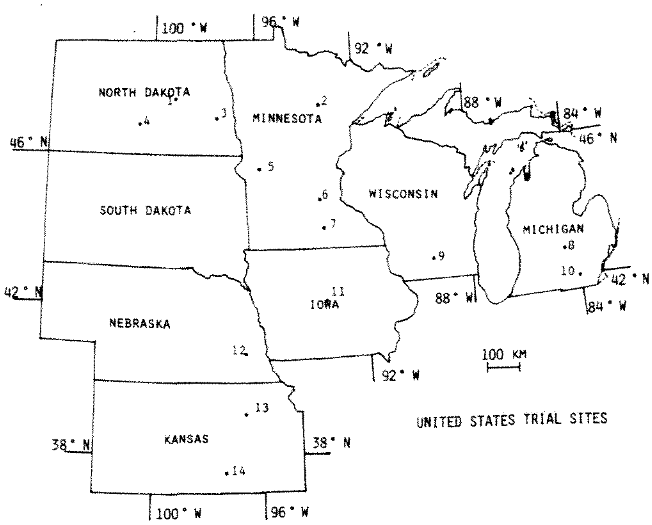

Fig. 2. Map of trial sites in the United States.
Legend. 1. Foster County, ND: North Dakota State University Carrington Research Center; 2. Itasca County, MN: University of Minnesota North Central Experiment Station; 3. Cass County, ND: North Dakota State University Research Arboretum; 4. Burleigh County, ND: Soil Conservation Service Bismarck Plant Materials Center; 5. Stevens County, MN: University of Minnesota West Central Experiment Station; 6. Carver County, MN: University of Minnesota Landscape Arboretum; 7. Waseca County, MN: University of Minnesota Southern Experiment Station; 8. Clinton County, MI: Soil Conservation Service Rose Lake Plant Materials Center; 9. Dane County, WI: University of Wisconsin Arboretum; 10. Lenawee County, MI: Michigan State University Hidden Lake Gardens; 11. Story County, IA: Iowa State University Horticulture Research Station; 12. Lancaster County, NE: University of Nebraska at Lincoln; 13. Riley County, KS: Soil Conservation Service Manhattan Plant Materials Center; 14. Sedgwick County, KS: Kansas State University Horticulture Research Center.

One to 20 (usually three) seedlings of each test population were transplanted to the field in at least seven of the 14 sites. Plant survival, size, and performance were recorded by cooperators and reported to the senior author one, five, and ten years after planting. Cultural conditions were not uniform among trial sites. Records describing cultural practices at each site can be obtained on request from the senior author.

Climatic data for sites in Yugoslavia were obtained from Furlan's review (8) and from the *Klimadiagramm Weltaltas* (21). Long-term climatic data for weather stations near test sites were obtained from *Climates of the States, 2nd ed.* (2). Yearly minimum temperatures for trial sites during the period 1975 to 1989 were provided by cooperators. Calculation of the moisture index, I_m, is based on long-term normals using the formula developed by Mather and Yoshioka (13):

$$I_m = 100 \, [(\text{annual mean precipitation} / \text{PE}) - 1].$$

Estimates of potential evapotranspiration (PE) at trial sites were taken from a map by Thornthwaite (18) and PE estimates for Yugoslavia came from the *Agro-climatic Atlas of Europe* (19).

Hardiness zones for Yugoslavia are taken from the work of Heinze and Schreiber (10) and those for the United States are taken from the *USDA Plant Hardiness Zone Map* (1). Both sources (1, 10) use the same zonation system. MSTAT statistical software (version 4.0) (14) was used for regression analyses to test climatic models.

Results and Discussion

Initial establishment. First-year survival of test populations was generally good (Table 2). Mean initial establishment was 71%, with 750 of 1063 plants alive after one year. Only four of 27 test populations had less than 50% survival: *Fraxinus ornus*, PI 385252; *Ostrya carpinifolia*, PI 377842 and PI 377845; and *Pinus nigra*, PI 399401. First-year reports indicated that many *P. nigra* seedlings were very small and hence established poorly and that most *F. ornus* seedlings were damaged or killed by low temperatures, but first-year reports on *Ostrya* were inconclusive. Another *Ostrya* population, PI 377841, had 100% first-year survival.

Tenth-year survival and plant performance. Of the 750 plants that survived the first year at trial sites, 713 were evaluated for the duration of the study. Five seedlings lost after the first winter were replaced and 42 other plants were removed from test plantings between the first and tenth years because of theft, thinning, or administrative decisions, and not by environmentally induced injury. In Table 2, the "corrected number alive after year one" includes only plants evaluated throughout the study.

Tenth-year survival was calculated as a percentage of the corrected number alive (Table 2). It accounts for survival during years two through ten, eliminating differences in initial establishment. Performance data from trial sites and tenth-year survival were analyzed to determine the range of adaptation for each test population. The 27 populations divided fairly evenly into three groups.

Widely adapted populations. The most promising group was made up of eight widely adapted populations representing three species, *Pinus nigra*, PI 399400 and PI 399401; *Pinus sylvestris*, PI 399402, PI 399403, and PI 399404; and *Viburnum opulus*, PI 399414, PI 399415, and PI 399416. These populations showed a range of tenth-year survival from 75 to 94% when averaged across trial sites. Selections of these species are already common in the nursery trade and are widely grown in the north central United States. Because these populations performed well at diverse sites, their potential as replacements for types currently in the trade will now be considered.

Performance records indicate that all three *V. opulus* populations may be superior to typical seedling populations in the trade and could be useful sources of new cultivars. These viburnums exhibited good to excellent growth and performance at nearly all sites. Once established, the plants grew in ten years to 1.8 to 3.3 meters (5.9–10.8 feet) tall [mean height 2.7 meters (8.9 feet)], with spreads of 1.3 to 3.8 meters (4.3–12.5 feet) [mean spread 2.6 meters (8.5 feet)]; there were no reports of serious injury. Flowers and fruits were very attractive, and one of the authors (DKW) selected a superior plant with darker red fruits for propagation and further evaluation. In some years, these populations displayed bright red autumn foliage along with heavy fruiting. A common pest of this species, the snowball aphid, *Neoceruraphis viburnicola* (Gillette), was a problem only at the Foster County, ND trial site.

The three *P. sylvestris* populations varied little in performance. They were sufficiently hardy, once established, at northern sites such as Cass County, ND and Itasca County,

Table 2. Initial establishment and tenth-year survival of test populations.

Taxon	PI number	No. planted (#)	First-year survival (%)	Corrected no. alive after year 1 (see text) (#)	Tenth-year survival (% of corrected no. alive) (%)
Acer campestre L.	399308	60	58	36	67
Acer opalus Mill. subsp. *obtusatum* (Waldst. & Kit.) Gams	399315	51	65	33	0
Carpinus betulus L.	377783	34	56	19	74
Euonymus europaeus L.	399360	46	63	29	62
Fraxinus excelsior L.	377816	36	86	24	63
Fraxinus excelsior L.	377817	36	100	31	48
Fraxinus excelsior L.	385251	40	95	38	39
Fraxinus ornus L.	385252	32	38	12	8
Juniperus communis L.	377822	30	87	26	73
Laburnum alpinum (Mill.) Bercht. & Presl	377829	26	69	18	0
Ligustrum vulgare L.	399377	32	69	22	59
Ostrya carpinifolia Scop.	377841	18	100	18	0
Ostrya carpinifolia Scop.	377842	29	45	11	18
Ostrya carpinifolia Scop.	377844	29	52	13	0
Ostrya carpinifolia Scop.	377845	25	40	10	0
Picea omorika (Pančić) Purkyně	399396	40	75	30	40
Pinus mugo Terra	377847	44	52	23	13
Pinus mugo Terra	399398	38	84	32	44
Pinus nigra Arnold	399400	49	84	40	78
Pinus nigra Arnold	399401	62	45	16	75
Pinus sylvestris L.	399402	60	78	46	88
Pinus sylvestris L.	399403	59	81	59	94
Pinus sylvestris L.	399404	53	81	43	88
Sorbus aria (L.) Crantz	399409	26	58	15	27
Viburnum opulus L.	399414	33	82	24	88
Viburnum opulus L.	399415	36	83	27	89
Viburnum opulus L.	399416	39	79	28	75

MN, but also performed well in Sedgwick County, KS. After ten years, the trees grew to 2.4 to 6.6 meters (7.9–21.7 feet) tall [mean height 4.0 meters (13.1 feet)] and 1.8 to 4.4 meters (5.9–14.4 feet) wide [mean spread 3.2 meters (10.5 feet)]. Winter needle color was blue-green.

Additional evidence supporting the utility of Yugoslavian populations of *P. sylvestris* comes from an extensive provenance test of *P. sylvestris* populations from Europe and Asia established in more than 40 sites in the northern United States (25). This test included a population collected in Yugoslavia that scored above-average ratings for both relative height and needle color at sites in Michigan, Missouri, and Nebraska. A later report of performance at the Nebraska site confirmed these ratings (16). Nevertheless, a long-term evaluation of 49 Eurasian provenances of *P. sylvestris* indicated that populations adapted to north central North Dakota came from Estonia, Ukraine, and Russia but not from sites farther south or west (3).

Pinus nigra populations, PI 399400 and PI 399401, were both cultivated at seven trial sites. At all seven sites, PI 399401 was slower growing than or was noted as inferior to PI 399400. Although its tenth-year survival was nearly as good as PI 399400, PI 399401 did show poor initial establishment (Table 2). The superior population, PI 399400, suffered winter injury in Stevens County, MN, Waseca County, MN, and Cass County, ND. This population did produce well-formed trees in Story County, IA, Riley County, KS, Sedgwick County, KS, Lenawee County, MI, Carver County, MN, and Dane County, WI, but is probably not a significant improvement over *P. nigra* populations typically grown in the region. Notably, it may be resistant to *Dothistroma pini* Hulbary, as no cooperator noted any needle diseases in this population.

Dothistroma needle blight has caused significant damage to *P. nigra* in the United States (15). An evaluation of 26 seedling populations of *P. nigra* for infection by *D. pini* found one highly resistant pine population (15). That population was the only one tested from Yugoslavia and it should be compared with PI 399400. The Yugoslavian population known to be resistant also was evaluated as part of an extensive provenance test (22), where it had above-average ratings for relative height at sites in Michigan, Nebraska, and Ohio.

The eight most promising populations, described above, were all collected in Slovenia, at elevations between 320 and 750 meters (1050–2460 feet) (Fig. 1, sites 2, 4, 6, 8, 10, and 11). *Pinus sylvestris* and *V. opulus* are common in northern Eurasian boreal forests (20), reaching the southern edge of their native ranges in Yugoslavia. *Pinus nigra* is a native of central and southern European montane forests (4, 22). The two *P. nigra* accessions tested were collected at fairly low elevations relative to typical stands in the region. These facts suggest that superior collections of European boreal and montane species may be made from populations in the warmer parts of their distributions. But reports of provenance tests of *P. nigra* and *P. sylvestris* (22, 25) serve as counter-examples. In those studies, pines from the warmest sites suffered more frequent winter injury than did populations from other sites.

Populations with limited adaptation. Ten populations were adapted at fewer sites than were the first group. These populations included eight different species, *Acer campestre*, *Carpinus betulus*, *Euonymus europaeus*, *Fraxinus excelsior*, *Juniperus communis*, *Ligustrum vulgare*, *Picea omorika*, and *Pinus mugo* (PI 399398 only). In general, they performed well at five sites (Story County, IA, Sedgwick County, KS, Clinton County, MI, Lenawee County, MI, and Dane County, WI); were inadequately tested at Riley County, KS and Lancaster County, NE; and were injured or lost at the other sites. They showed a range of tenth-year survival from 39 to 74% when averaged across trial sites.

Acer campestre, PI 399308, was recently noted as one of the best-performing test populations at the Story County, IA, site (11), but was injured or killed by cold in Minnesota and North Dakota. The three *F. excelsior* populations, PI 377816, PI 377817, and PI 385251, were often damaged by lilac borers, *Podosesia syringae* (Harris), and banded ash clearwings, *Podosesia aureocincta* Purrington & Nielsen, limiting their utility even where hardy. *Euonymus europaeus*, PI 399360; *J. communis*, PI 377822; *L. vulgare*, PI 399377; and *P. mugo*, PI 399398, were inferior in aesthetic quality and in adaptation to improved cultivars used in the region.

Picea omorika, PI 399396, was an exception to this general pattern. It performed well at three sites in Minnesota and at the Wisconsin site, but grew poorly elsewhere. Dirr (5) considered *P. omorika* among the most handsome of spruces. He commented that there are fine specimens growing in a wide range of environments in the eastern United States from Maine to Kentucky. Considering the restricted native range of this species, steep limestone slopes along a single river valley (4), its broad adaptation may seem unusual. On the basis of analyses of enzyme polymorphisms and seedling morphology, however, Kuittinen et al. (12) have recently reported that *P. omorika* is remarkably variable genetically.

Unadapted populations. The final group of nine unadapted populations includes all populations of five species not commonly grown except in the mildest and most-protected locations in the north central United States: *Acer opalus* subsp. *obtusatum*, *Fraxinus ornus*, *Laburnum alpinum*, *Ostrya carpinifolia*, *Sorbus aria*, and one population of *Pinus mugo*, PI 377847. Winter injury and drought stress killed most seedlings in this group, with tenth-year survival between 0 and 27% when averaged across trial sites.

The few plants that survived ten years did so despite injuries caused by environmental stresses, with the exception of two of ten seedlings of *P. mugo*, PI 377847, tested at Itasca County, MN. After ten years, these two surviving seedlings became attractive, low-growing shrubs about 0.9 meters (3 feet) tall and 1.6 meters (5.25 feet) wide. Slow-growing forms of *P. mugo* often perform well in foundation plantings, but may suffer in open-field tests because of weed competition and losses from mechanical injury. The accession, PI 377847, was collected on Mt. Maglić at an elevation of 1240 meters (4070 feet) (Fig. 1, site 23), the highest collection site. In addition to slow growth rates, plants from higher elevation sites may be poorly adapted to summer heat. The Itasca County, MN trial site, where two seedlings performed well, has the coolest summers of all trial sites, [July mean temperature = 19.5°C (67.1°F)].

Performance by test site and climatic comparisons. Table 3 summarizes population survival at each trial site. In addition to measures discussed in the previous section (i.e., first-year survival and tenth-year survival), an additional measure, overall survival, is included. Overall survival, a measure of survival for the duration of the test, was calculated by multiplying first-year survival by tenth-year survival.

Table 3. **Plant survival at trial sites.**

Trial site	First-year survival (%)	Tenth-year survival[z] (%)	Overall survival (%)
Iowa, Story County	78	42	33
Kansas, Riley County	90	91	82
Kansas, Sedgwick County	87	55	48
Michigan, Clinton County	93	89	83
Michigan, Lenawee County	83	61	51
Minnesota, Carver County	88	54	48
Minnesota, Itasca County	70	47	33
Minnesota, Stevens County	44	57	25
Minnesota, Waseca County	56	46	26
Nebraska, Lancaster County	67	31	21
North Dakota, Burleigh County	25	10	3
North Dakota, Cass County	50	49	24
North Dakota, Foster County	28	48	13
Wisconsin, Dane County	77	31	24

[z]Measured as a percentage of the corrected number of plants alive after year 1 (see Table 2).

Trial sites differed widely in all three measures of plant survival (Table 3). The most difficult site was in Burleigh County, ND, where only a single plant of *Viburnum opulus*, PI 399415, survived after ten years. In contrast, overall survival exceeded 80% at trial sites in Riley County, KS and Clinton County, MI.

The roles of temperature and moisture in explaining these differences were tested with multiple-regression analysis. Three climatic factors calculated for each trial site, January mean temperature (T_{Jan}), July mean temperature (T_{Jul}), and the moisture index (I_m), were regressed to determine relative contributions of cold, heat, and drought to plant loss among trial sites. Two-way multiplicative interactions also were tested to see if they would strengthen the models.

For first-year survival (S_1), the best regression model is

$$S_1 = 0.0270\ T_{Jan} + 0.0076\ I_m + 0.8884\ (R^2 = 0.841,\ P \leq 0.001).$$

This model includes only January mean temperature and the moisture index. It predicts that the best first-year survival will be at sites with high January mean temperatures and high moisture indices. The inclusion of July mean temperature or any interaction factors did not improve the predictive value of this model.

None of the models tested explained a significant proportion of the variation in tenth-year survival (S_{10}). This may be due to the effects of particularly harsh sites. On such sites, S_1 was extremely low so that only the hardiest plants survived even the first year, leading to inflated values of S_{10} at harsh sites and serving to confound any linear climatic model. The confounding effect of harsh sites is eliminated by examining overall survival (S_O). The best regression model for S_O resembles that for S_1:

$$S_O = 0.0279\ T_{Jan} + 0.0047\ I_m + 0.6064\ (R^2 = 0.558,\ P = 0.011).$$

As for the S_1 model, this model only includes January mean temperature and the moisture index.

There are subtle yet important differences between these two models. First, a comparison of coefficients shows that each models' coefficient for January mean temperature is nearly the same, but that coefficients for moisture index differ. Perhaps, under these test conditions, the moisture regimen is proportionally more important for establishment in the year after transplanting than for survival once root systems are more fully developed. Second, the lower R^2 for the S_O model (the statistical significance of the difference in R^2 values is marginal, $P = 0.16$) indicates that non-climatic factors at trial sites, such as soil types and degree of care, may be more important determinants of overall survival than of first-year survival.

A direct comparison of climatic conditions at collection sites with those at trial sites (Table 4) lends heuristic support to the two models. Collection sites in Yugoslavia tend to be warmer in winter, cooler in summer, and more moist than the trial sites. Hardiness zones for collection sites range from 6b to 9a, whereas all trial sites are zone 6a or colder. Although high-elevation collection sites are somewhat colder than low-elevation sites and are generally within the range of January mean temperatures at trial sites, high-elevation sites also have much higher moisture indices, in all instances beyond the range of values for trial sites.

When used to estimate values of first-year and overall survival, given January mean temperatures and moisture indices from collection sites, the models verify the expectation that these plants are well adapted to their native climates. Estimates of first-year survival in collection-site climates range from 0.88 to 1.0, and overall-survival estimates range from 0.60 to 1.0.

In the north central United States, the best climatic analogs to Yugoslav conditions occur in southwestern Michigan and northeastern Ohio. For example, Cleveland, OH and Benton Harbor, MI, have values of −3.5°C (25.7°F) for January mean temperature, 22°C (71.6°F) for July mean temperature, 40 for moisture index, and −27 to −28°C (−16.6–−18.4°F) for absolute minimum temperature (2).

Many authors have stressed the importance of extreme climatic events in determining plant adaptation (9, 10, 17, 24). Because January mean temperature was a significant determinant of first-year and overall survival, we also analyzed two measures of extreme low-temperatures at trial sites. The first measure, T_{min}, is the average yearly minimum temperature at each trial site for 1975 to 1989. Hardiness zones are based on the categorization of long-term T_{min} (1, 10). The second measure, F_{min}, is the proportion of years with minimum temperatures below −32°C (−25.6°F) for 1975 to 1989. This limit approximates the absolute minimum temperature recorded at the coldest collection sites (Table 4).

For trial sites in this study, T_{Jan}, T_{min}, and F_{min} are highly correlated, with all pairwise r^2 values above 0.85 ($P \leq 0.001$). With such high correlations, it is not surprising that substituting T_{min} and F_{min} for T_{Jan} gives very similar regression models to those using T_{Jan}. For T_{min},

$$S_1 = 0.0292\ T_{min} + 0.0078\ I_m + 1.5062\ (R^2 = 0.843,\ P \leq 0.001) \text{ and}$$
$$S_O = 0.0309\ T_{min} + 0.0048\ I_m + 1.2671\ (R^2 = 0.575,\ P = 0.008).$$

And for F_{min},

$$S_1 = -0.3744\ F_{min} + 0.0074\ I_m + 0.7858\ (R^2 = 0.833,\ P \leq 0.001) \text{ and}$$
$$S_O = -0.3590\ F_{min} + 0.0046\ I_m + 0.4892\ (R^2 = 0.510,\ P = 0.019).$$

Differences in the relative strengths and predictive value of the three regression models for S_1 and for S_O were tested. There were no significant differences in R^2 values (lowest $P = 0.82$) among either the three regression models for S_1 or among the models for S_O. Potential biases in predictive value among regression models for S_1 and S_O were examined by comparing predicted rankings of sites for plant survival with actual rankings. In all cases, Spearman coefficients of rank correlation for these comparisons were significant at the $P \leq 0.001$ level.

Twenty-seven seedling populations from a broad array of landscape trees and shrubs from Yugoslavia were evaluated for adaptation at 14 sites in the north central United States. After a ten-year evaluation, these populations could be divided into three groups. Eight populations were widely adapted, ten were adapted to some sites, and nine were unadapted in the region. The most promising plants in this trial included widely adapted populations of *Viburnum opulus*, *Pinus sylvestris*, and *Pinus nigra*. There also were plants such as *Acer campestre* and *Picea omorika* that could be successfully introduced to some parts of the region. *Pinus*

Table 4. Climatic summaries for collection sites and trial sites.

Location	T_{Jan}(°C)	T_{Jul}(°C)	I_m	Absolute min. temperature (°C)	Hardiness zones
Slovenia & Croatia:					
low elevation (350–500 m)	−2 to 2	19 to 22	0 to 75	−22 to −16	6b to 7b
high elevation (500–1100 m)	−4 to −2	16 to 19	75 to 150	−32 to −22	6b to 7a
Bosnia & Hercegovina:					
low elevation (400–800 m)	−3 to 2	17 to 22	0 to 50	−20 to −16	7a to 8b
high elevation (800–1240 m)	−5 to 0	15 to 18	25 to 125	−30 to −20	7a to 8a
F. ornus (Figure 1, site 24)	3	21	100	−15	9a
Trial Sites	−14.5 to −0.5	19.5 to 27	−30 to 20	−43 to −29	3b to 6a

nigra populations from Yugoslavia should be considered where Dothistroma needle blight is severe.

Temperature and moisture data were analyzed with multiple regression models to elucidate statistical relationships between plant adaptation and climate. Significant regression models were identified that relate low temperatures and moisture conditions at trial sites with plant survival. January mean temperatures, mean annual minimum temperatures, and the frequency of annual minimum temperatures below −32°C (−25.6°F) were interchangeable measures of low temperature in these models. A comparison of climatic conditions at collection sites in Yugoslavia with those at trial sites indicates that Yugoslavian climates are analogous only to the most moderate sites in the north central United States.

On the basis of these evaluations and the regression models, we suggest that it would be productive to make additional collections of landscape plants for testing in the north central United States from regions in eastern Europe meeting certain criteria: January mean temperatures should be at or below −5°C (23°F) and July mean temperatures should be at least as warm as the collection sites in Yugoslavia, perhaps above 18°C (64.4°F). There should be moderate, annual moisture deficits and elevations should be below approximately 1000 meters (3280 feet). The identification of such regions and their potentially useful plants awaits further study and exploration.

Literature Cited

1. Cathey, H.M. 1990. USDA Plant Hardiness Zone Map. USDA-ARS Misc. Publ. 1475.

2. Climates of the States. Second Ed. 1980. Gale Research, Detroit. 2 volumes, 1175 p.

3. Cunningham, R.A., and D.F. Van Haverbeke. 1991. Twenty-two year results of a Scots pine (*Pinus sylvestris* L.) provenance test in North Dakota. USDA-FS Research Paper RM-298.

4. den Ouden, P., and B.K. Boom. 1965. Manual of Cultivated Conifers. 1978 reprinting. M. Nijhoff, The Hague. 526 p.

5. Dirr, M.A. 1983. Manual of Woody Landscape Plants. Third Ed. Stipes Publishing Co., Champaign, IL. 826 p.

6. Dodge, A.F., W.L. Ackerman, and H.F. Winters. 1965. Performance of three privet introductions in the upper midwest. Amer. Hort. Mag. 44(2):92–98.

7. Flynn, R.E., and G. Quinting. 1983. Gazetteer of Yugoslavia. Second Ed. Defense Mapping Agency, Washington, DC. 2 volumes, 874 p.

8. Furlan, D. 1977. The climate of southeast Europe. World Survey of Climatology 6:185–235.

9. George, M.F., M.J. Burke, H.M. Pellett, and A.G. Johnson. 1974. Low temperature exotherms and woody plant distribution. HortScience 9:519–522.

10. Heinze, W., and D. Schreiber. 1984. Eine neue Kartierung der Winterhärtezonen für Gehölze in Europa. Mitteilungen der Deutsches Dendrologisches Gesellschaft 75:11–56.

11. Iles, J.K., and M.P. Widrlechner. 1992. Recommended landscape plants from the heartland. Amer. Nurseryman 175(11):20–27.

12. Kuittinen, H., O. Muona, K. Kärkkäinen, and Ž. Borzan. 1991. Serbian spruce, a narrow endemic, contains much genetic variation. Can. J. For. Res. 21:363–367.

13. Mather, J.R., and G.A. Yoshioka. 1968. The role of climate in the distribution of vegetation. Ann. Assoc. Amer. Geogr. 58:29–41.

14. Nissen, O., E.H. Everson, S.P. Eisensmith, V. Smail, J. Anderson, K. Rorick, G. Portice, D. Rittersdorf, P. Wolberg, M. Weber, R. Freed, B. Bricker, T. Heath, and J. Tohme. 1985. MSTAT Version 4.0. Michigan State University, East Lansing.

15. Peterson, G.W., and R.A. Read. 1971. Resistance to *Dothistroma pini* within geographic sources of *Pinus nigra*. Phytopathology 61:149–150.

16. Read, R.A. 1971. Scots pine in eastern Nebraska: A provenance study. USDA-FS Research Paper RM-78.

17. Sakai, A. 1978. Freezing tolerance of evergreen and deciduous broad-leaved trees in Japan with reference to tree regions. Low Temperature Science, Series B 36:1–19.

18. Thornthwaite, C.W. 1948. An approach toward a rational classification of climate. Geographical Rev. 38:55–94.

19. Thran, P., and S. Broekhuizen. 1965. Agro-climatic Atlas of Europe. PUDOC, Wageningen. n.p.

20. Tutin, T.G., V.H. Heywood, N.A. Burges, D.M. Moore, D.H. Valentine, S.M. Walters, and D.A. Webb (Editors). 1964–1980. Flora Europaea. Cambridge University Press, Cambridge. 5 volumes, 2260 p.

21. Walter, H., and H. Lieth. 1960–1964. Klimadiagramm Weltatlas. VEB Gustav Fischer Verlag, Jena. 2 volumes, n.p.

22. Wheeler, N.C., H.B. Kriebel, C.H. Lee, R.A. Read, and J.W. Wright. 1976. 15-year performance of European black pine in provenance tests in north central United States. Silvae Genetica 25:1–6.

23. Widrlechner, M.P. 1990. NC-7 regional ornamental trials: evaluation of new woody plants. METRIA Proceedings 7:41–47.

24. Woodward, F.I. 1987. Climate and Plant Distribution. Cambridge Univ. Press, Cambridge, 174 p.

25. Wright, J.W., S.S. Pauley, R.B. Polk, J.J. Jokela, and R.A. Read. 1966. Performance of scotch pine varieties in the north central region. Silvae Genetica 15:101–110.