BRANCH MORPHOLOGY IN YOUNG POPLAR CLONES ON FLOODPLAIN SITES IN MISSOURI

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ABSTRACT.—Four *Populus* clones were grown in central Missouri for 2 years at 1 x 1 m spacing to study total biomass production on floodplain sites previously in forage grasses. Branch morphology (living, first-order proleptic, and sylleptic shoots) was assessed for 2-year-old plants. All 2-year-old plants had lateral branches, and clones varied signi-ficantly in certain branch attributes. A *Populus deltoides* x *P. nigra* hybrid (I45/51) had significantly more branches, greater total branch length and more branches per unit height than did three *P. deltoides* clones (26C6R51, 2059, 1112) derived from Midwest region collections. Further, I45/51 carried a greater proportion of its branches on the lower stem than did *P. deltoides* clones. Whereas intense branching often occurred below 50 cm height in the hybrid clone, *P. deltoides* plants often were clear of branches below 1 to 2 m. Mean angles of branch origin were similar among clones (46.9° to 51.1°) with no significant differences. Length-weighted vector averages of branch azimuth indicated that there was a significant trend toward greater branch growth on the south side of trees, but little apparent clonal variation in this attribute. The profuse branching habit of the hybrid I45/51 was closely associated with its high second-year leaf area index and biomass production.

Populus L. (poplar) species have been incorporated into numerous managed systems for production of timber and fiber. Such culture provides a variety of benefits both economic and environmental. Poplars, and especially their hybrids, have displayed a prodigious capacity for rapid biomass accretion (Anderson and others 1983, Heilman and Stettler 1985, Ranney and others 1987). The rapid growth rates of poplars are related to unit leaf area rates of photosynthesis (which are among the highest of all woody plants (Nelson 1984)), as well as to leaf area production and display. Area-based productivity of poplars depends on planting density and the rate at which canopy closure can be attained. Branch growth and orientation largely govern this process.

Genetic variation in many traits, including growth rate, within species and among hybrids of *Populus* species is well documented. Poplar photosynthesis is under genetic control and sensitive to environmental conditions (Regehr and others 1975, Liu and Dickmann 1993, Rhodenbaugh and Pallardy 1993). Previous work has also shown that poplar clones vary phenotypically in rate and duration of branch and leaf area production and in display characteristics (Isebrands and others 1983, Michael and others 1988, Scarascia-Mugnozza and others 1997). These traits are often highly heritable (Wu 1994, Wu and Stettler 1994, 1996). Hence study of the structure and function of promising clones can aid in selection, tree improvement, and distribution programs.

Despite the popularity of poplar culture and study of poplar biology in other parts of the U.S. (e.g., Pacific Northwest and the Lakes States), there has been little systematic study of the suitability of poplars for use in short-rotation plantations in the lower Midwest, and no study of morphological determinants of growth in genotypes distributed to the public by state agencies. Here we present information on branch morphology, canopy attributes, and growth of four, 2-year-old poplar clones grown in short rotation plantations established in the floodplain of the Missouri River in central Missouri.

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PLANTATION ESTABLISHMENT

Hardwood cuttings of three eastern cottonwood (*Populus deltoides* Bartr.) and one *P. deltoides* x *Populus nigra* L. hybrid clone (table 1) were planted in May 1999 in a former tall fescue (*Festuca arundinacea* Schreb.) pasture on the Missouri River floodplain at the University of Missouri's Horticulture and Agroforestry Research Center at New Franklin, MO (Lat. 39º 01′, Long. 92º 46'). Before planting the site was treated with a non-selective herbicide to eliminate grass competition. A randomized complete block design similar to that of Scarascia-Mugnozza and others (1997) was employed, with six replicates (blocks) each consisting of four single-clone plots (7 rows x 10 columns). Spacing was 1 x 1 m (10,000 trees/ha).

Planted cuttings showed good shoot emergence in May, but in June there was substantial mortality in some clones. This required replanting with potted cuttings and transplanting from some blocks so that a number of complete blocks would be available for each clone. Ultimately the number of complete blocks (of an original six) available per clone was: six for I45/51, five for 1112, three for 2059, and two for 26C6R51. Plants were watered frequently during the first growing season to maintain high soil moisture in the top 30 cm, but not during the second year when growing season rainfall (May-September) was adequate (52.3 cm, 102 percent of average).

Height and diameter growth in years one and two were measured for 79 "permanent plot" trees throughout the plantation (17 to 24 trees per clone). Some destructive harvesting was conducted in the plantation to develop biomass prediction equations, but buffer trees were maintained at all adjacent positions around each permanent plot tree.

BRANCH ANALYSES

For the present work, after the second growing season five to six trees per clone were selected for detailed study. In randomly chosen blocks the mean diameter of permanent plot trees was computed and permanent plot trees of approximately this diameter were designated for study. Measurements began at the first branch from the bottom upward. Data obtained were: total tree height and diameter, main stem branch number, branch height above ground, branch length from collar to tip of bud, branch orientation in degrees clockwise from due North, angle of branch origin (acute angle made by the ascending branch to the main stem on the apical side) and terminal leader length. If the lead stem had been cut or damaged, or if two main stems had formed, the dominant stem was considered the main stem and not measured as a branch. Dead branches, which comprised less than 10 percent of total branches, were not measured.

During the second growing season, Leaf Area Index (LAI) and canopy gap estimates were obtained monthly for each plot using a LI-COR LI-2000 Canopy Analyzer (LI-COR, Inc., Lincoln, NE).

Height, stem base diameter, d^2h (a proxy variable for volume), main stem branch number, number of branches per m height, branch length from collar to tip of bud, total branch length per tree, angle of branch, terminal leader length and mid-season (early August) LAI were analyzed via Analysis of Variance. Branch length data were square-root transformed after Nelson and others (1981). Least squares means were computed and means comparisons were conducted (via SAS LSMEANS probabilities) if overall ANOVA results provided a significant F-test ($p < 0.05$).

Table 1.— *Origin and source information for four* Populus *clones grown in a short rotation plantation in central Missouri*

Clone	Parentage	Source	Origin	Latitude	Longitude
I45/51	*P. deltoides*Iowa x *P. nigra*	State Tree Nursery	——	——	——
26C6R51	*P. deltoides*	Missouri Department of Conservation Nursery	Pope County, IL	37º 25′	88º 34′
2059	*P. deltoides*	Missouri Department of Conservation Nursery	Osage County, MO	38º 27′	91º 52′
1112	*P. deltoides*	Missouri Department of Conservation Nursery	New Madrid County, MO	36º 35′	89º 37′

Crown orientation was assessed for all sampled trees by vector averaging (Stull 1995) in two ways, using:

1) unit vectors (branch length = 1 for all branches) and
2) branch length-weighted vector averages.

These data were tested using contingency table analysis for statistically significant trends in N-S and E-W orientation by comparing the number of trees having averaged vectors with some component of N- or E-facing orientation (i.e., 270 to 90º and 0 to 180º, respectively) vs. those with S- and W-facing orientation (90 to 270º and 180 to 360º, respectively). Patterns of branch distribution along the stem were analyzed by goodness-of-fit tests using χ^2 of pooled branch numbers above and below the midpoint between ground level and the highest branch insertion height, with an equal distribution above and below as the null hypothesis.

RESULTS AND DISCUSSION

Plants of all clones typically had excurrent form as shown in figure 1 with lateral branches on lower stems and long terminal leaders, as has been previously reported in *Populus* spp. grown at close spacing (e.g., Dawson and others 1976, Ceulemans and others 1988).

At a finer scale the 2-year-old plants exhibited clonal differences in morphology (table 2). The *Populus deltoides* x *P. nigra* hybrid clones (I45/51) had significantly more ($p \leq 0.05$) branches, greater total branch length, and more branches per unit height than did the three *P. deltoides* clones (26C6R51, 2059, 1112) derived from Midwest region collections.

Whereas intense branching often occurred below 50 cm in height in the hybrid clone, the first live branch of *P. deltoides* clones occurred 1 to 2 m high on the stem. This pattern resulted in significant differences in branch distribution above and below the midpoint of the branching region (i.e., excluding the terminal leader length), with two *P. deltoides* clones (26C6R51, 1112) exhibiting more branches above the midpoint, one clone (2059) with equal distribution, and one clone (I45/51) having branches significantly weighted toward the lower portion of the branching region (table 3).

Nelson and others (1981) also noted development and retention of lower branches in 4-year-old hybrid *Populus* clones grown in short-rotation intensive culture plantations in Wisconsin. The pattern of branching displayed by I45/51 may promote diameter growth, as photosynthate produced by leaves displayed lower in the crown often is preferentially allocated to cambial growth (Larson and Gordon 1969). In fact, mean second-year stem diameter in I45/51 was greater than that of all *P. deltoides* clones (table 4). The diameter differences between clone

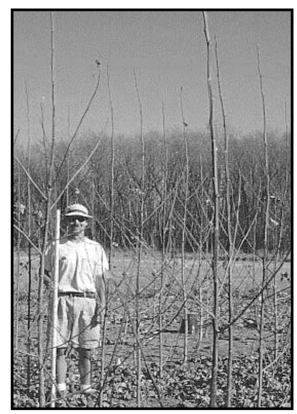

Figure 1.—*Appearance of* P. deltoides *x* P. nigra *clone I45/51 (upper) and* P. deltoides *clone 1112 (lower) in November, 2000, after two seasons of growth on a floodplain, formerly-pastured site in central Missouri.*

Table 2.—*Mean values of branch attributes for 2-year-old* Populus *clones grown in a short-rotation plantation in central Missouri*

Clone	Branch angle (º)	Total branch length (m)	Branches/m height	Number of branches	Terminal leader length (m)
I45/51 (n=6)	51.1	22.61 a	6.4 a	30.0 a	1.20
26C6R51 (n=5)	50.2	10.72 b	4.1 b	17.4 b	1.30
2059 (n=6)	46.9	10.25 b	2.5 b	11.8 b	1.78
1112 (n=5	49.2	8.48 b	2.5 b	10.0 b	1.92

[1] Within a column means not followed by the same letter are significantly different ($p < 0.05$).

Table 3.—*Percent of branch insertions above and below the midpoint of total branch insertion regions of the main tree stem for* Populus *clones. Asterisks indicate significant departures from an equal distribution as the null hypothesis by pooled* c^2*;* *"ns" indicates a lack of significant departure from an equal distribution.*

Clone above midpoint	Percent above midpoint	Percent below midpoint
I45/51	23.5	76.5*
26C6R51	73.6	26.4*
2059	57.7	42.3^{ns}
1112	98.0	2.0*

Table 4.—*Mean values of stem attributes for 2-year-old* Populus *clones grown in a short-rotation plantation in central Missouri*

Clone	Height (m)	Diameter (cm)	d^2h (cm^3 x10^{-2})	Mid-season leaf area index
I45/51 (n=24)	4.67 a	4.67 a	109.7 a	3.98 a
26C6R51 (n=14)	3.58 b	3.52 b	30.0 b	2.37 b
2059 (n=21)	5.19 a	4.15 ab	94.9 ab	2.40 b
1112 (n=20)	4.33 ab	3.67 b	60.2 b	2.26 b

[1] Within a column means not followed by the same letter are significantly different ($p < 0.05$).

I45/51 and clones 1112 and 26C6R51 were statistically significant ($p \leq 0.05$).

Branch distribution between the two height growth increments (HGI) appeared to vary within and among clones (fig. 2). Whereas clone 1112 produced very few to no branches in the second year, clone 26C6R51 had many more first-order branches on the second HGI. Clones 2059 and I45/51 exhibited greater plant-plant variation in HGI distribution patterns and branch distribution on both HGIs. Although I45/51 had some second-year HGI branches, there were far more first-year HGI branches in all plants.

Proportional distribution of branch length along the vertical sequence of branch insertion indicated roughly symmetrical distribution of branch length up the stem in three of four clones (fig. 3). Although there was some plant-plant variation, plots of percent branch length versus percent cumulative branches approximated a 1:1 ratio in clones 2059, 26C6R51 and I45/51. In contrast, in four of five plants of clone 1112, relative branch lengths were longer at upper branch insertion points, with the remaining plant largely adhering to the 1:1 relationship observed for other clones.

Mean vertical angles of branch origin were similar (46.9° to 51.1°) with no significant differences among clones (table 2). These values are in the low- to mid-range of previously-reported branch angles for young, closely spaced *Populus* clones of diverse parentage (Nelson and others 1981, Wu and Stettler 1994). Vector averages of branch azimuth indicated that there was a tendency for net branch growth to be greater on the south side of trees (fig. 4). This trend toward a S-facing orientation was significant ($p \leq 0.05$) for branch length-weighted vectors based on a χ^2 test of goodness-of-fit based on a null hypothesis of even N-S distribution. There was little indication of clonal variation in this attribute (not shown). These data suggest that crown architecture responds to the directional nature of the light regime, placing more foliage on the south side of the crown, which in the Northern Hemisphere receives more direct growing season radiation.

Overall, branch morphology in these *Populus* clones was related to several growth attributes. For example, the profuse branching habit of hybrid I45/51 was closely linked with higher mid-season LAI in this clone and the highest value of d^2h, which is closely related to volume growth (tables 2 and 4). Canopy gap estimates for I45/51 at this time were about 5 percent (data not shown), indicating full canopy closure at 1 x 1 m spacing by the second year of growth. Larson and Gordon (1969) also noted the association of abundant branches lower on the stem with greater diameter growth in this clone.

Data from biomass estimation studies (unpublished) indicated that second-year, above- and below-ground biomass also was highest in clone I45/51 (17.7 mt ha^{-1}). The *P. deltoides* clones had sparser branching characteristics that were reflected in lower LAI values (table 4) and higher canopy gap estimates (data not shown). For clones 1112 and 26C6R51 these morphological patterns were associated with smaller second-year biomass (10.62 and 8.42 mt ha^{-1}, respectively). However, it is interesting to note that clone 2059 exhibited volume and biomass growth closer to that of the hybrid clone (second-year biomass estimates of 16.1 mt ha^{-1}) despite dissimilar canopy characteristics. These data suggest

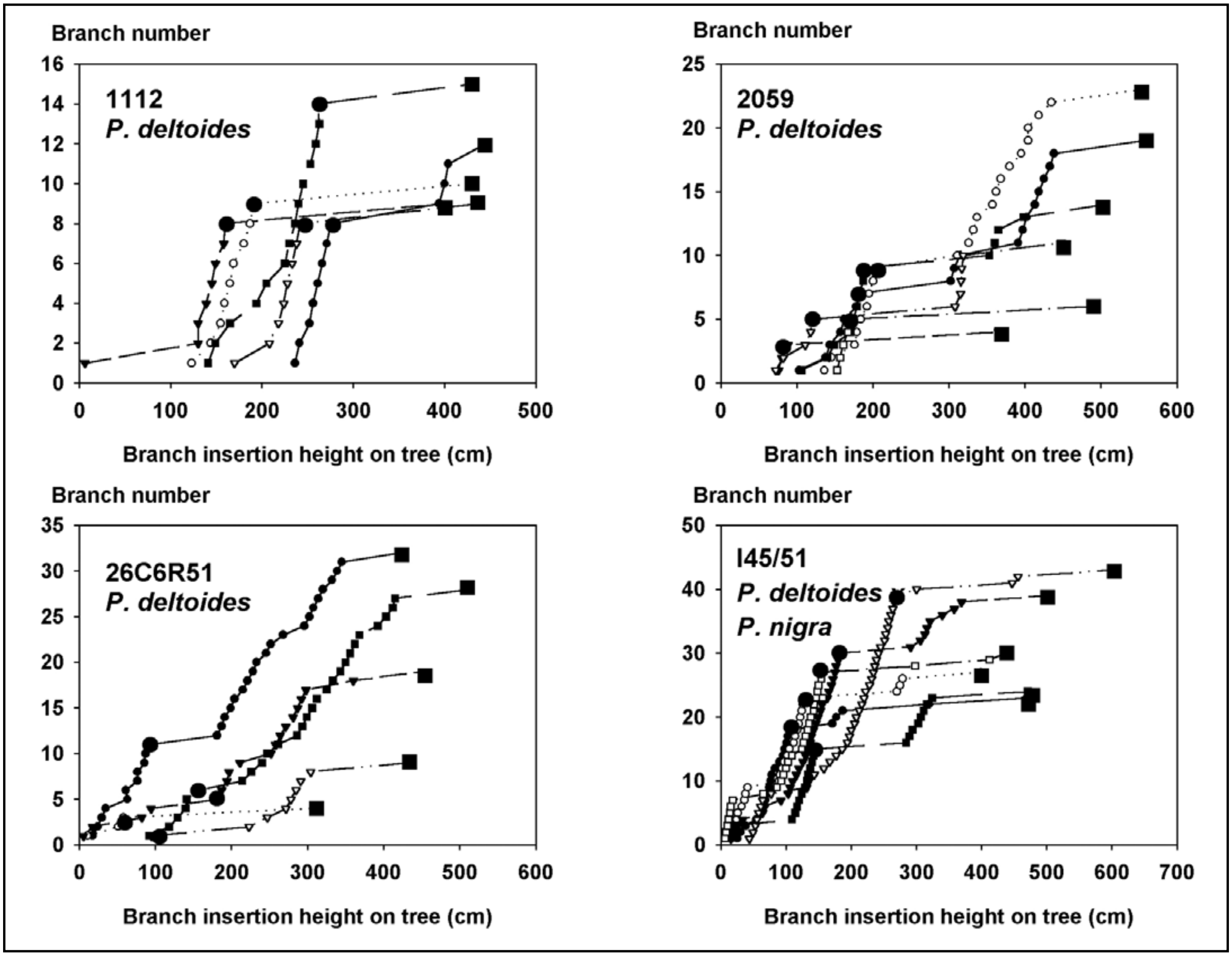

Figure 2.—*Vertical distribution of branches along the stems of four, 2-year-old* Populus *clones. Each trace represents one plant. Large filled circles and squares indicate the limit of first- and second-year height growth increment (HGI), respectively.*

higher photosynthetic capacity and/or assimilation efficiency in clone 2059 than in other clones.

CONCLUSION

Two-year-old clones exhibited significant variations in several branch morphology attributes, primarily relating to branch number, length, and distribution along the main stem. These differences may be partially responsible for associated differences in LAI and growth in plantation culture.

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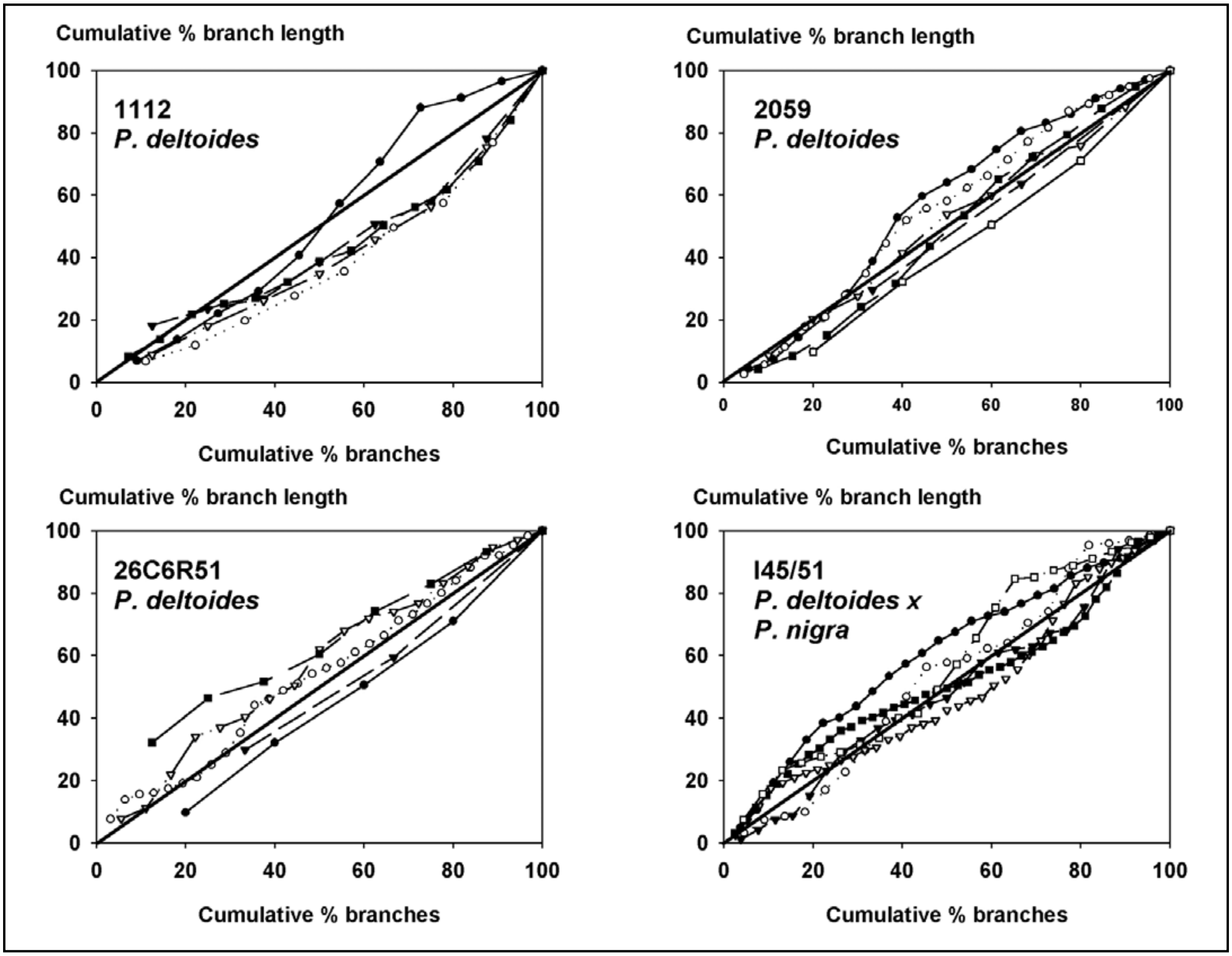

Figure 3.—*Proportional distribution of total branch length (as percent) versus cumulative percent total branches (0 percent = stem base) of four, 2-year-old* Populus *clones. Each trace represents one plant. Heavy line indicates a 1:1 ratio.*

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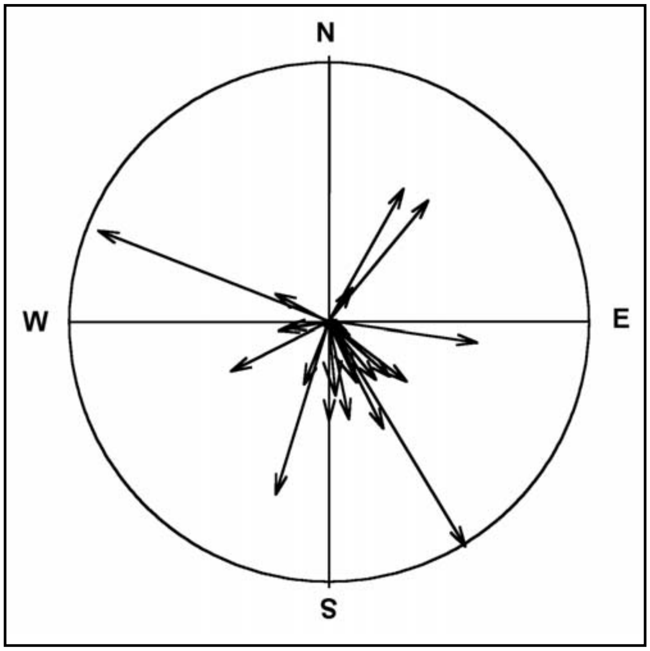

Figure 4.—*Branch length-weighted vector averages of branch azimuth orientation of all plants of sampled* Populus *clones. Each vector arrow represents one plant.*

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