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John A. Sprackling

Ralph A. Read

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JOHN A. SPRACKLING AND RALPH A. READ

CONSERVATION AND SURVEY DIVISION
INSTITUTE OF AGRICULTURE AND NATURAL RESOURCES
THE UNIVERSITY OF NEBRASKA–LINCOLN

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Authors John A. Sprackling, Forestry Research Technician, and Ralph A. Read, Principal Silviculturist, are both staff members of the Forestry Sciences Laboratory of the U.S. Forest Service, Rocky Mountain Forest & Range Experiment Station, Lincoln, Nebraska. Central headquarters is maintained at Fort Collins, Colorado, in cooperation with Colorado State University. The Forestry Sciences Laboratory is maintained in cooperation with the Agricultural Experiment Station of the Institute of Agriculture and Natural Resources, The University of Nebraska—Lincoln.

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INTRODUCTION

During the dust bowl days of the 1930s, there was considerable anxiety about the success of planting trees on the Great Plains. Not all trees brought in for their scenic beauty or growth habits were equal to the harsh Plains climate. Generally, the survival of seedlings on the dry, windy prairies depended on the ability of the seedlings to establish deep roots during the first few years, thereby ensuring survival during droughts.

Now in the 1970s, there is again considerable interest in the establishment of trees on the Great Plains. The U.S. General Accounting Office (GAO) alerted Congress in 1975 to recent widespread removal of shelterbelts to accommodate center-pivot irrigation systems. The GAO reported that unless actions were taken to encourage farmers to renovate and preserve existing windbreaks, an important national resource would be lost and croplands would be exposed to severe wind erosion.

The Conservation and Survey Division of the University of Nebraska, under direction of the late George E. Condra, a staunch supporter of tree planting, conducted an intensive study of tree roots in the eastern half of Nebraska during the years 1939 to 1941. This study, supervised by the late M. B. Jenkins, was funded by the federal government through the Work Projects Administration (WPA) with the dual objectives of providing employment and of obtaining information concerning the root distribution patterns of various tree species.

The results of the study were never published and the voluminous data compiled over the 3 years were almost lost in the ensuing years. In time, however, the data were transferred to the Forestry Sciences Laboratory on the East Campus of the University of Nebraska–Lincoln, where they were stored for more than a decade.

The data and detailed drawings presented in this paper emanate from the aforementioned study, which was prematurely terminated when World War II began. The authors' selection of illustrations from the voluminous files should enable the reader to compare root distribution systems of major tree and shrub species growing under different soil-moisture conditions in eastern Nebraska. About two-thirds of these are native species; the remainder are well adapted introductions. Root distribution characteristics contributing to drought-hardiness are herein noted.

The authors express their appreciation to the late George E. Condra and the late Eugene C. Reed, former directors of the Conservation and Survey Division, and expecially to the late M. B. Jenkins in acknowledgment of the many man-hours involved in collecting these data. We suspect that the late J. E. Weaver of the Botany Department of the University of Nebraska may also have had much to do with the technical aspects of this study, for his painstaking research on root systems of plants was classic and internationally acknowledged. We wish we could list the names of all who worked on this project, but that information is unavailable.

REVIEW OF PAST RESEARCH

Bunger and Thomson (1938) excavated windbreak trees growing in silt loam soils in the panhandle of Oklahoma, categorizing species there into three groups according to root depths. Deep-rooted species, those with roots below 15 feet, were Siberian elm *(Ulmus pumila),* Osage-orange *(Maclura pomifera),* eastern redcedar *(Juniperus virginiana),* and black locust *(Robinia pseudoacacia).* Siberian elm and Osage-orange roots grew to a depth of 27 feet. Medium-rooted species, those with roots reaching 10 to 15 feet below soil surface, were Russian mulberry *(Morus alba* f. *tatarica)* and honeylocust *(Gleditsia triacanthos).* Shallow-rooted species, with roots penetrating less than 10 feet, were apricot *(Prunus armeniaca),* ash *(Fraxinus* sp.), and black walnut *(Juglans nigra).*

Yeager (1935) studied root systems of trees growing on clay prairie soils near Fargo, North Dakota, and found that 97 percent of tree roots there were in the top 4 feet of the soil. He concluded that drought-resistant species, such as oak *(Quercus* spp.*)* and chokecherry *(Prunus virginiana),* developed deep root systems regardless of soil-moisture conditions. Species that are not drought-resistant, such as boxelder *(Acer negundo),* silver maple *(Acer saccharinum),* green ash *(Fraxinus pennsylvanica),* cottonwood *(Populus* spp.*),* and willow *(Salix* spp.*),* formed shallow roots on dry sandy sites but had a tendency to grow deep vertical roots on very moist (non-saturated) sandy sites.

Weaver (1920) recognized that roots of herbs and forbs growing in a grassland formation exhibit distinctive species characteristics, presumably inherited yet modified by different environmental factors. Certain species, because of their genetic makeup, develop taproots; other species grow strong lateral root systems (Weaver and Clements 1938). Deep initial root growth is a genetic characteristic of eastern redcedar, pignut hickory *(Carya glabra)*, and American chestnut *(Castanea dentata)*, which is expressed consistently whether on dry or wet soil. Nevertheless, environmental conditions somewhat modify root structure following initial growth in the above species. In contrast, initial root growth of red maple *(Acer rubrum)* responds immediately to environmental conditions. On wet soils, seedlings form shallow, widespread initial roots; but on dry soils they grow narrow, deep initial roots (Toumey and Korstian 1928).

Research has consistently shown that soil texture and the corresponding soil-moisture condition are important environmental influences on root structure. Anderson and Cheyney (1934) studied seedlings of Norway pine *(Pinus resinosa)*, white spruce *(Picea glauca)*, and Fraser fir *(Abies fraseri)*. They concluded that seedlings grown in fine-textured (moist) soils produced fewer lateral rootlets, whereas those grown in coarse-textured (drier) soils produced more lateral rootlets. Taproots were deeper in coarse-textured than in fine-textured soils. The mechanical resistance of the soils, as determined by pore space, was the most important factor modifying the hereditary traits of the taproot. Haasis (1921) found that the branching of ponderosa pine *(Pinus ponderosa)* seedling roots was decreased by clay soils and increased by loam soils. He found that roots branched most on very coarse soils but, contrary to Anderson and Cheyney, had the shallowest roots.

Boldt and Singh (1964) determined root development patterns of ponderosa pine 1, 2, and 4 years after transplanting in cultivated silt loam soil at Lincoln, Nebraska. Root systems of these trees showed two distinct types: strong vertical penetration and wide lateral distribution. Roots of all three trees showed rapid growth in depth, the oldest tree reaching the water table at 6.5 feet in 3 years. Lateral root development was exceedingly rapid, with main laterals extending radially 8 to 13 feet in 4 years.

Impermeable soil layers, hardpans, and permanently saturated soils (high water tables) reduce soil aeration and curtail root growth. Insufficient oxygen in the soil causes root growth to cease and leads to root mortality if this condition becomes permanent (Kramer and Kozlowski 1960). Many examples of the influence of a shallow (high) water table on root distribution are illustrated in the following figures.

MATERIALS AND METHODS

A total of 543 trees and shrubs representing 53 different native or introduced species were excavated and measured. Root drawings and data for 39 of these species (table 1) are herewith presented. All trees and shrubs sampled were growing naturally or were in plantings at four locations: (1) northeastern Nebraska: Dakota and Thurston counties; (2) Platte River valley of east-central Nebraska: Nance and Merrick counties; (3) the uplands of east-central Nebraska: Lancaster County; and (4) southeastern Nebraska: Pawnee and Richardson counties (see figure 1).

A complete description of the tree and site was given for each excavation, including the species, age, tree height, root depth, root spread, soil series, soil texture in A and B horizons, slope position, aspect, and depth to water table.

Two types of excavations were made to measure root depth and spread. Trees 5 years old and younger were totally excavated. Trees over 5 years of age were partially excavated: a 3-foot-wide trench, dug directly under the middle of the root crown, extended in opposite directions as far and as deep as the roots. A grid of 1-foot squares was marked on the vertical sides of the trench, and the root system was sketched. Tree age was determined from ring counts by increment borer or by felling the smaller trees.

The following ratios were computed for each tree: (1) root depth/tree height, (2) root spread/tree height, and (3) root depth/root spread. Data from 392 of the trees were used in presenting the average ratios for 12 of the most common tree species in Nebraska (tables 2 and 3). These species were selected for tabular comparison, because they were sampled sufficiently to obtain reliable averages. Root drawings of these and other tree species common in Nebraska are presented for comparison.

RESULTS AND DISCUSSION

The 12 most common species are tabulated in order of average root depth/tree height (d/h) ratios in table 2. This arrangement is approximately in order of greatest to least drought-resistance; that is, the closer the ratios approach 1.00 or greater, the deeper are the roots in relation to the tree heights. Root spread/tree height (s/h) ratios are also shown in table 2. The same species are listed according to root depth/root spread (d/s) ratios, and according to age classes, from seedlings to older trees (table 3).

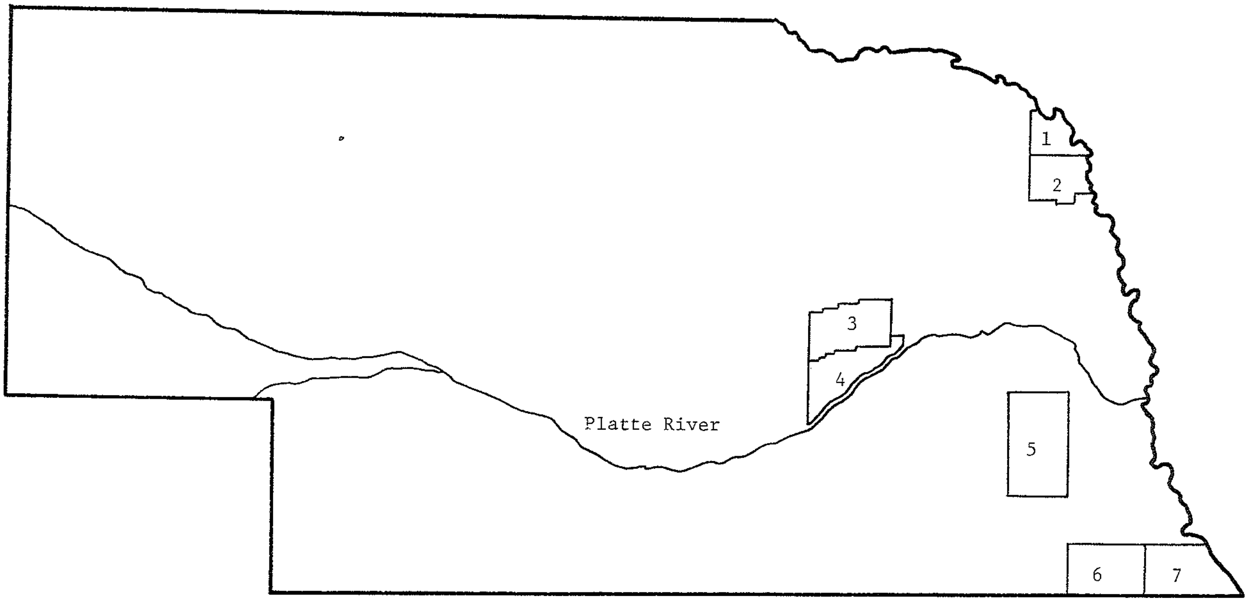

Fig. 1. The study area included seven counties in eastern Nebraska: 1 — Dakota; 2 — Thurston; 3 — Nance; 4 — Merrick; 5 — Lancaster; 6 — Pawnee; and 7 — Richardson.

Table 1

Common and scientific names of trees and shrubs

Common name	Scientific name
Apple (York Imperial)	*Malus pumila* Mill.
Apricot	*Prunus armeniaca* L.
Ash (green)	*Fraxinus pennsylvanica* Marsh.
Ash (white)	*Fraxinus americana* L.
Basswood	*Tilia americana* L.
Black locust	*Robinia pseudoacacia* L.
Boxelder	*Acer negundo* L.
Buckeye (Ohio)	*Aesculus glabra* var. *glabra* Willd.
Catalpa (northern)	*Catalpa speciosa* Warder
Cherry (black)	*Prunus serotina* Ehrh.
Chokecherry	*Prunus virginiana* L.
Coffeetree (Kentucky)	*Gymnocladus dioicus* (L.) K. Koch
Cottonwood (Plains)	*Populus deltoides* var. *occidentalis* Rydb.
Dogwood	*Cornus alternifolia* L.
Elm (American)	*Ulmus americana* L.
Elm (slippery)	*Ulmus rubra* Mühl
Elm (Siberian)	*Ulmus pumila* L.
Hackberry	*Celtis occidentalis* L.
Hawthorn	*Crataegus mollis* Scheele
Hickory (bitternut)	*Carya cordiformis* (Wangenh.) K. Koch
Hickory (shagbark)	*Carya ovata* (Mill.) K. Koch
Hophornbeam (ironwood)	*Ostrya virginiana* (Mill.) K. Koch
Honeylocust	*Gleditsia triacanthos* L.

TABLE 1 (Continued)

Maple (silver)	*Acer saccharinum* L.
Mulberry (red)	*Morus rubra* L.
Mulberry (Russian)	*Morus alba* f. *tatarica* Seringe
Oak (bur)	*Quercus macrocarpa* Michx.
Osage-orange	*Maclura pomifera* (Raf.) Schneid.
Pine (Rocky Mountain ponderosa)	*Pinus ponderosa* var. *scopulorum* Engelm.
Plum (American)	*Prunus americana* Marsh. var. *americana*
Prickly-ash	*Zanthoxylum americanum* Mill.
Redbud (eastern)	*Cercis canadensis* L. var. *canadensis*
Redcedar (eastern)	*Juniperus virginiana* L.
Russian-olive	*Elaeagnus angustifolia* L.
Sumac (smooth)	*Rhus glabra* L.
Sycamore (American)	*Platanus occidentalis* L.
Walnut (black)	*Juglans nigra* L.
Willow (black)	*Salix nigra* Marsh.
Willow (peachleaf)	*Salix amygdaloides* Anderss.

Bur oak has the deepest root structure in relation to height, with an average ratio of 0.62 (table 2). This means that roots extend downward 0.62 feet for every foot of tree height. Bur oak's ecological niche is along the tension zone between prairie and forest. A pioneer species, it tends to invade prairie grasslands with or after the *Rhus-Symphoricarpos-Corylus* chapparal type, where fire is controlled (Weaver and Kramer 1932). The species occupies very dry prairie sites in the central Great Plains, extending westward along bluffs of streams on well-drained upland sites. It is undoubtedly the most drought-resistant broadleaf species growing in the Great Plains. The characteristic deep taproot enables trees of this species to reach moisture unavailable to shallow-rooted species. Water tables are frequently less than 20 feet below soil surface in some areas of Nebraska, and deep-rooted species can draw upon this source of moisture.

Bur oak in the first 5 years has the deepest roots in relation to lateral spread (d/s = 1.26). Compare table 3. Weaver and Kramer (1932) found that taproots of bur oak seedlings usually extend to a depth of 9 inches before leaves appear above ground. They found seedling roots on cultivated soil at depths of 5 feet after one growing season, 7 feet after two growing seasons, and 9.5 feet after three growing seasons. This rapid initial vertical root growth explains why bur oak seedlings survive on dry sites in the grassland prairies whereas shallow-rooted seedlings of other species may not last through the first growing season.

Hackberry and honeylocust are considered drought-resistant and listed high in table 2 with above-average d/h ratios. Black walnut, red mulberry, eastern cottonwood, and green ash, listed in the middle of table 2, have average drought-resistance.

In contrast, peachleaf willow has the shallowest root system in relation to height (d/h = 0.23). This species is nearly always found on bottomland sites, along streams and lakes, where soil is usually very moist and occasionally saturated. Undoubtedly the least drought-resistant of the 12 species, it is listed last in table 2.

American elm and boxelder, both bottomland species that are not drought-resistant, are listed with below average d/h ratios in table 2. These species and peachleaf willow have also the lowest s/h ratios. Apparently American elm, boxelder, and peachleaf willow have comparatively shallow and narrow root systems in relation to their heights.

Thus, with three exceptions, the order in which the 12 species are listed in table 2 tends to reflect a drought-tolerance gradient, with the most drought-resistant species having the highest d/h ratios. One exception is black walnut which has a 0.48 d/h ratio, the same as honeylocust even though it is not as drought-resistant as honeylocust. The second exception is Siberian elm which does well on dry, windy, difficult

Table 2

Twelve species ranked by average ratios

Species	Depth/height		Spread/height		Basis: number of trees
	ratio	s*	ratio	s*	
Oak, bur	0.62	0.47	1.32	1.07	26
Hackberry	0.50	0.37	2.00	1.02	32
Honeylocust	0.48	0.27	2.09	0.85	15
Walnut, black	0.48	0.28	1.86	1.17	18
Redcedar, eastern	0.45	0.33	1.56	0.82	23
Mulberry, red	0.44	0.30	1.57	0.50	20
Cottonwood, plains	0.42	0.52	1.23	0.88	32
Ash, green	0.41	0.31	1.25	1.02	59
Elm, Siberian	0.40	0.31	1.36	0.58	67
Elm, American	0.37	0.27	1.22	0.63	57
Boxelder	0.29	0.17	0.93	0.43	29
Willow, peachleaf	0.23	0.24	0.87	0.37	14
Mean (all species)	0.42		1.39		
Total number of trees					392

*Standard deviation

Table 3

Average root depth/root spread (d/s) ratios

Species	Age class (years)					Mean (all ages)
	2-5	6-10	11-25	26-49	>49	
Oak, bur	1.26 (4)*	—	0.53 (7)	0.55 (7)	0.34 (8)	0.59 (26)
Ash, green	0.65 (9)	0.62 (2)	0.36 (17)	0.42 (19)	0.25 (12)	0.41 (59)
Cottonwood, plains	0.47 (16)	0.59 (1)	0.22 (10)	0.43 (4)	0.39 (1)	0.39 (32)
Boxelder	1.00 (1)	0.64 (2)	0.36 (18)	0.26 (5)	0.15 (3)	0.36 (29)
Redcedar, eastern	0.93 (3)	0.21 (4)	0.22 (6)	0.29 (10)	—	0.34 (23)
Elm, American	0.57 (11)	0.35 (3)	0.32 (16)	0.25 (24)	0.26 (3)	0.34 (57)
Willow, peachleaf	1.18 (1)	0.40 (4)	0.25 (7)	0.14 (2)	—	0.34 (14)
Elm, Siberian	0.50 (19)	0.25 (45)	0.30 (3)	—	—	0.32 (67)
Walnut, black	0.45 (4)	0.31 (3)	0.34 (6)	0.19 (3)	0.20 (2)	0.32 (18)
Hackberry	0.39 (10)	0.55 (5)	0.14 (12)	0.23 (5)	—	0.30 (32)
Mulberry, red	0.46 (6)	0.30 (3)	0.20 (7)	0.19 (4)	—	0.29 (20)
Honeylocust	0.36 (8)	0.16 (1)	0.16 (3)	0.14 (2)	0.35 (1)	0.27 (15)
Mean (all species)	0.55 (92)	0.31 (73)	0.30 (112)	0.32 (85)	0.26 (30)	0.36 (392)

*Number in parenthesis indicates the number of trees on which the average is computed.

sites where other species fail. Siberian elm should probably rank about the same as hackberry. The third exception is eastern redcedar which ranks next to bur oak in drought-resistance. Like bur oak, the eastern redcedar seedling develops a long fibrous root system in relation to top growth during the first year, enabling the young tree to obtain soil moisture while minimizing water loss through transpiration. The rapid vertical root growth in relation to lateral development of 2- to 5-year-old eastern redcedar is above average, which is reflected in table 3 (d/s = 0.93). These data indicate that vertical root development of all species is very rapid during the first 5 years and that lateral root growth is not extensive until after the age of 5 years.

Standard deviations (s) for the average root depth/tree height (d/h) ratios were relatively large (table 2). Much of the extreme variations in root structures found within species appears to be a result of site differences. Root plasticity, or lack of it, depending on the inherent characteristics of a species, has very likely determined the extent of a tree's response to site differences.

The effect of soil texture on depth and spread of roots could not be determined because excavation sites were not evenly distributed over a wide variety of soil textures. All sites were in eastern Nebraska and most were classified as silt loam soils. High water tables were most important among the site factors that limited vertical root growth. In Nance County, 60-foot trees were found growing where the water table was only 2.5 feet below soil surface.

Root sketches of the trees illustrate the great variations found within and among the species encountered in this study. They are presented in order of drought-resistance as follows: figures 2 to 18, much drought-resistance; figures 19 to 43, average drought-resistance; figures 44 to 62, little drought-resistance.

CONCLUSION

Tree species have certain identifiable root patterns, yet extreme variations in root systems exist within and among the species. Soil texture, position on slope, aspect, and precipitation are all site factors that contribute to variation in root structure, yet it was not possible in this study to determine accurately the relative importance of each factor. It is apparent, however, that on sites where the water table is near the soil surface, all species produce shallow, wide-spreading root systems. This was especially evident in Nance County where the water table was often reported to be within 2 to 3 feet of the soil surface. In comparing the root systems of the 12 tree species, it was apparent that bur oak, the most drought-resistant broadleaf native in the central Great Plains, had the deepest root structure in relation to tree height. Hackberry and honeylocust, both drought-hardy, also had relatively deep root systems. Bottomland species such as peachleaf willow, boxelder, and American elm, which are less drought-resistant, had relatively shallow root systems.

In searching for trees to introduce to the central Great Plains for windbreaks, greenbelts, and landscape plantings, we should therefore favor species that produce rapid vertical root growth and maintain a high ratio of root depth/tree height during the first few years. These species have the characteristics needed for survival under the dry conditions that frequently exist in the prairies.

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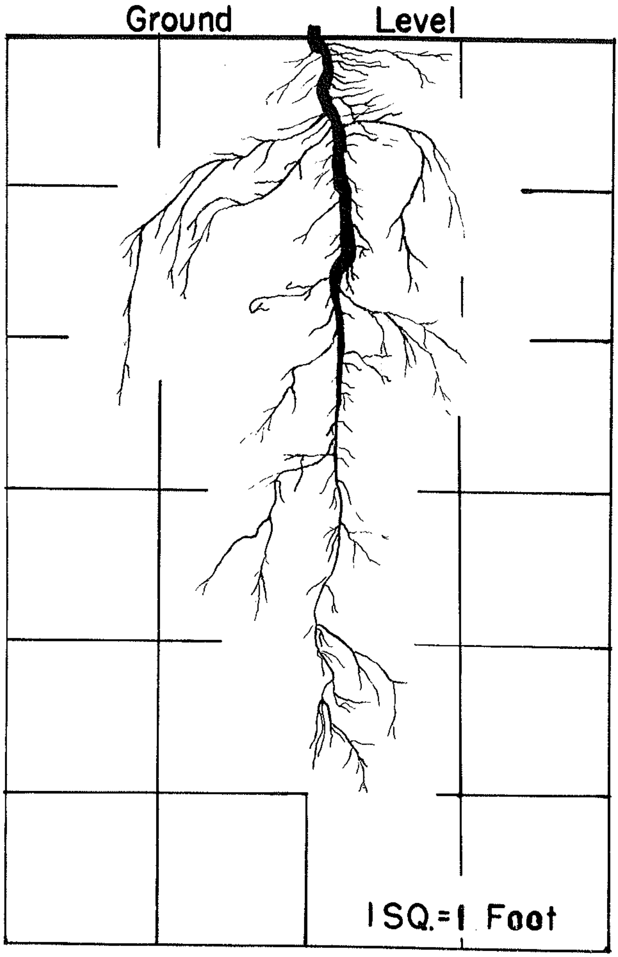


Fig. 2. Bur oak: 3 years, 3.5 feet tall, water table 20 feet, Wabash silt loam, Lancaster County. Bur oak roots penetrate rapidly. Root depth was 5 feet and lateral spread was only 2.5 feet (d/s = 2.00).

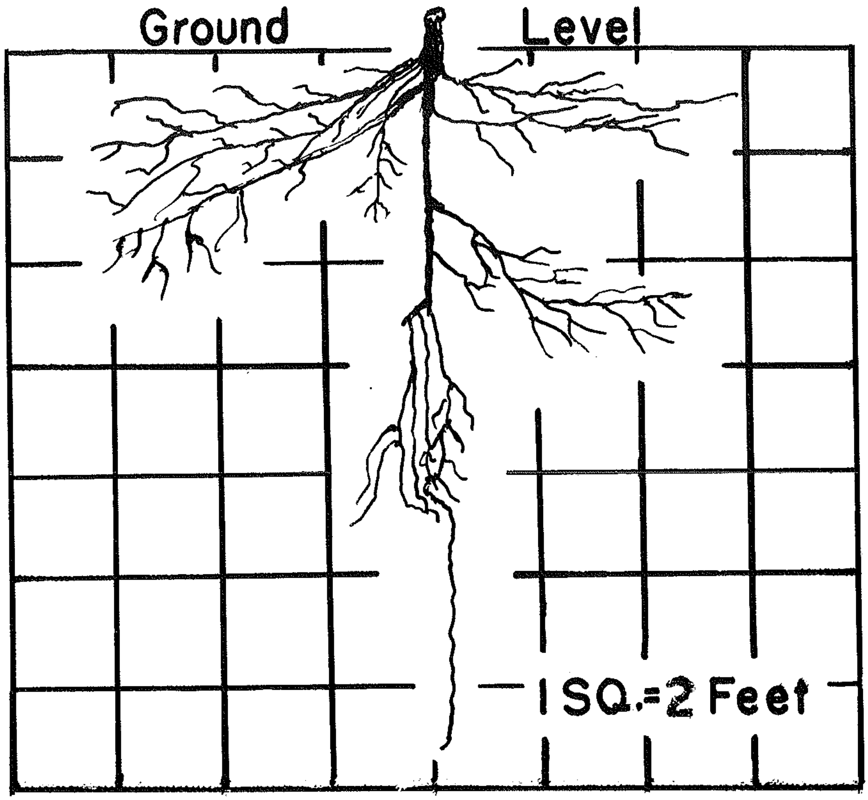


Fig. 3. Bur oak: 12 years, 14 feet tall, water table 70 feet, Knox silt loam, Richardson County. This sapling bur oak had a root depth of 13 feet and spread of 11.5 feet (d/s = 1.13). Compare that with figure 2 to see how lateral root growth increases as vertical growth slows with age.

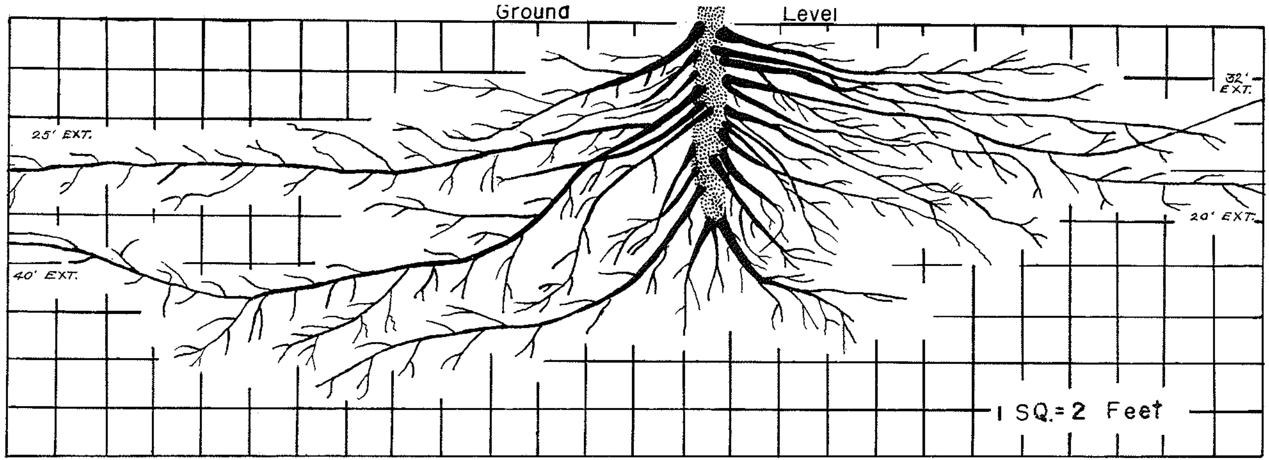


Fig. 4. Bur oak: 80 years, 20 feet tall, water table 50 feet, Peorian and Loveland loess, Nance County. The rate of lateral root growth in older trees is greater than the rate of depth penetration. Root depth, 16 feet; lateral spread, 72 feet (d/s = 0.21).

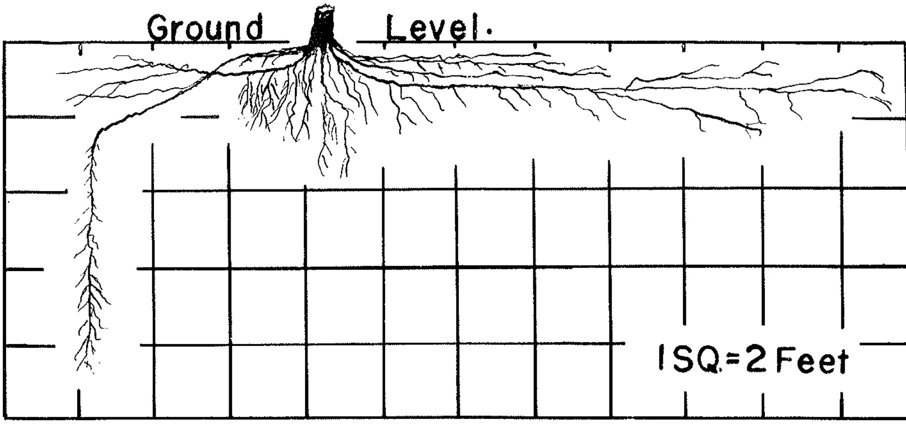


Fig. 5. Eastern redcedar: 40 years, 18 feet tall, water table 11 feet, Cass sandy loam, Merrick County. No taproot is apparent, but roots on left side have extended 9 feet downward to within 2 feet of the water table (d/h = 0.47).

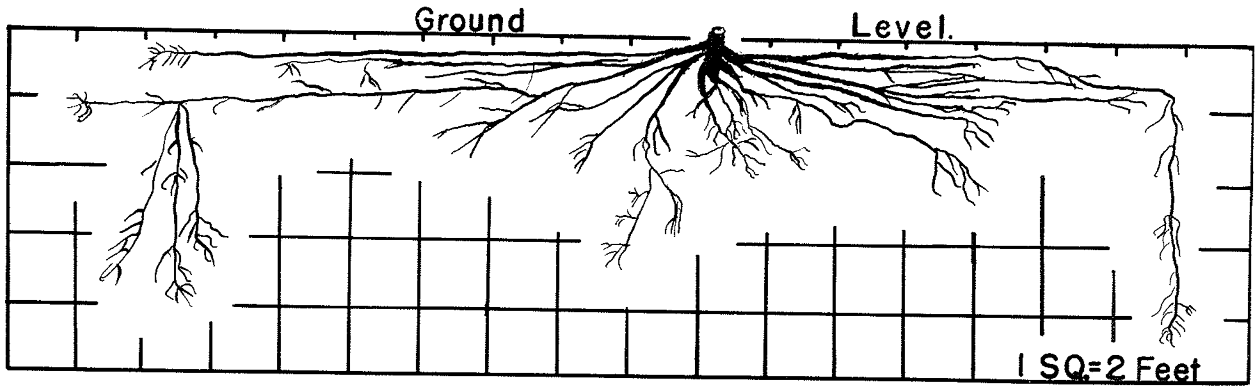


Fig. 6. Eastern redcedar: 40 years, 20 feet tall, water table 11 feet, Waukesha fine sandy loam, Merrick County. Strong development of a lateral system has been followed by downward penetration from laterals to within 2 feet of the water table.

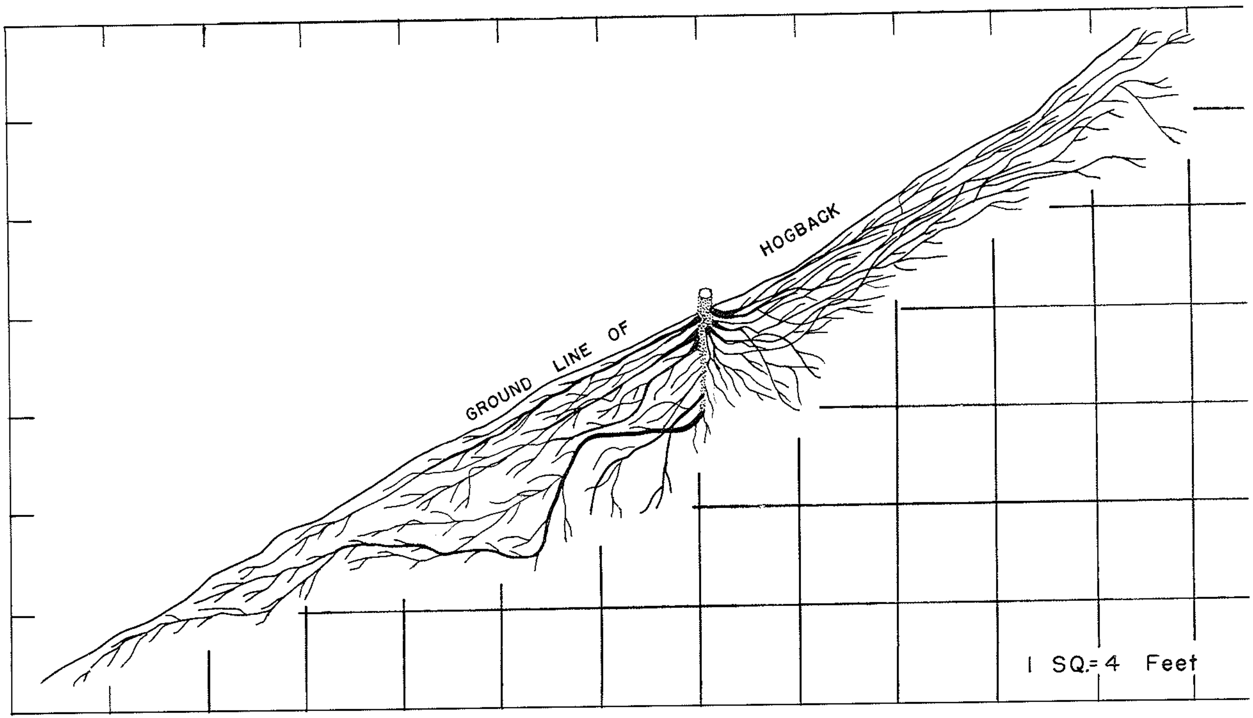


Fig. 7. Eastern redcedar: 34 years, 14 feet tall, water table 150 feet, Peorian loess, Nance County. This tree was growing on a hogback on the north face of a bluff. The main vertical root has alternately grown downward and laterally, maintaining a certain proximity to the soil surface.

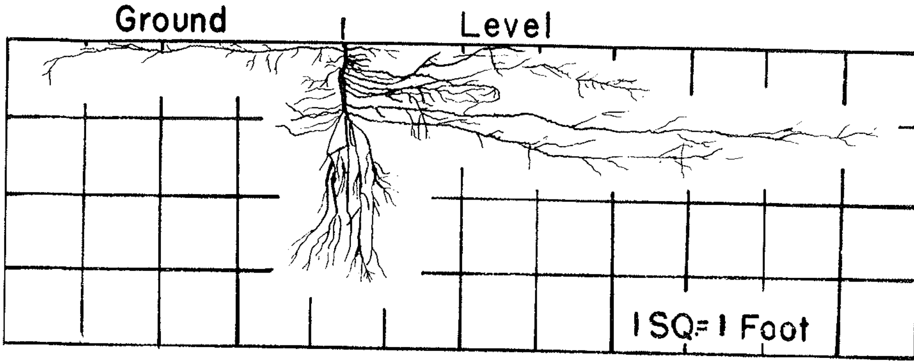


Fig. 8. Ponderosa pine: 4 years, 2 feet tall, water table 20 feet, Wabash silt loam, Lancaster County. The root system of this seedling was quite deep in relation to tree height (d/h = 1.60). The drought-resistance that ponderosa pine exhibits in the Great Plains is undoubtedly related to the early growth of deep roots.

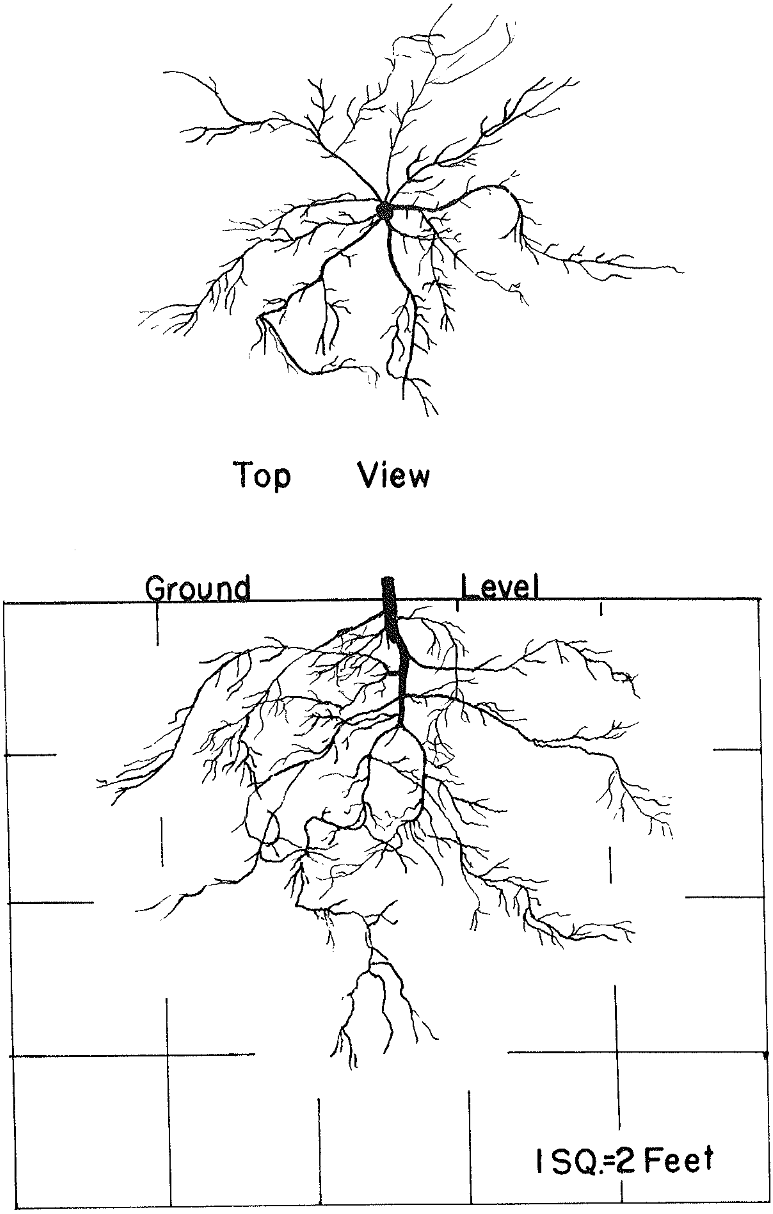


Fig. 9. Hackberry: 7 years, 6 feet tall, water table 15 feet, Wabash clay loam, Lancaster County. Roots of this sapling penetrated rapidly to a depth of over 6 feet; lateral roots (d/s = 0.85), shown in top view, developed symmetrically.

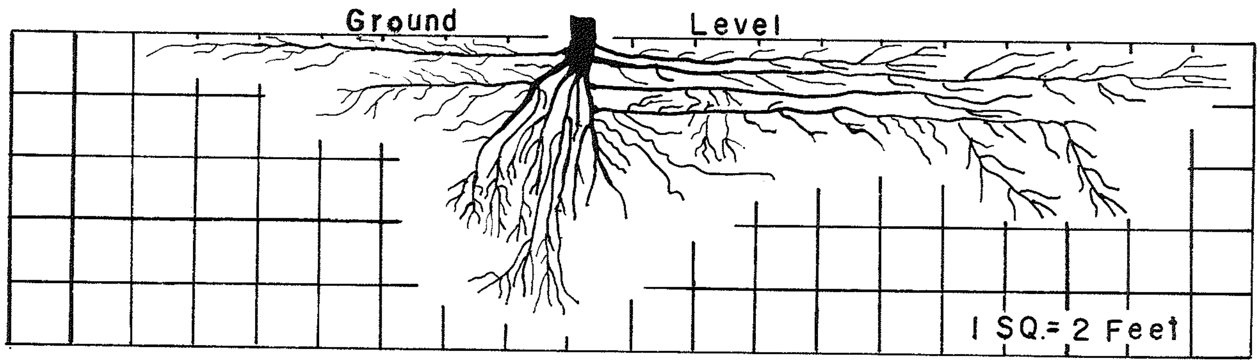


Fig. 10. Hackberry: 25 years, 19 *feet* tall, water table 45 *feet*, Wabash silt loam, Nance County. The rapid penetration in root depth of young seedlings (see figure 9) has stabilized at 9 *feet* in this tree, being followed by the extensive development of a strong lateral system (d/s = 0.25).

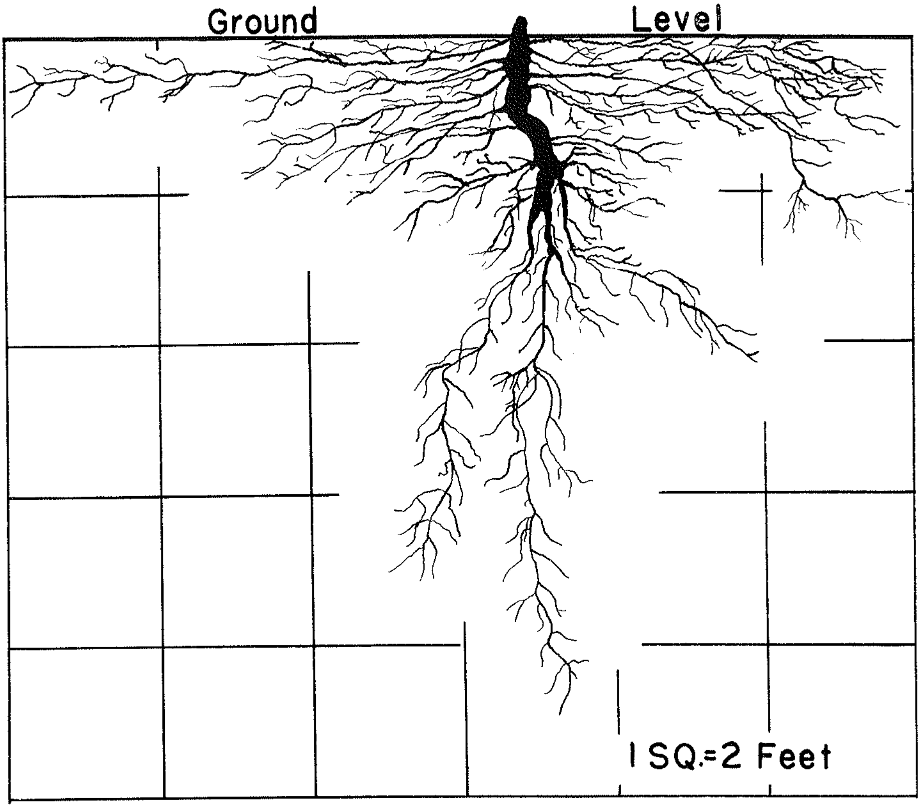


Fig. 11. Honeylocust: 3 years, 7 feet tall, water table 20 feet, Wabash silty loam, Lancaster County. Depth of taproot at 9 feet in 3 years exceeded the tree height (d/h = 1.29).

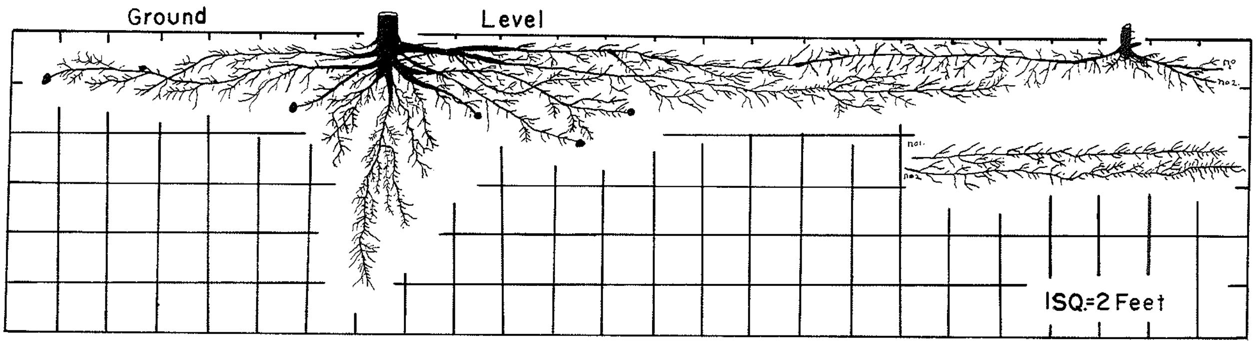


Fig. 12. Honeylocust: 28 years, 25 feet tall, water table 20 feet, Wabash silty clay loam, Pawnee County. Development of the lateral root system at depths of 1 to 3 feet is extensive (d/s = 0.15). A taproot, not well developed at this age, is evident. Note the natural root graft between the adjacent honeylocust trees.

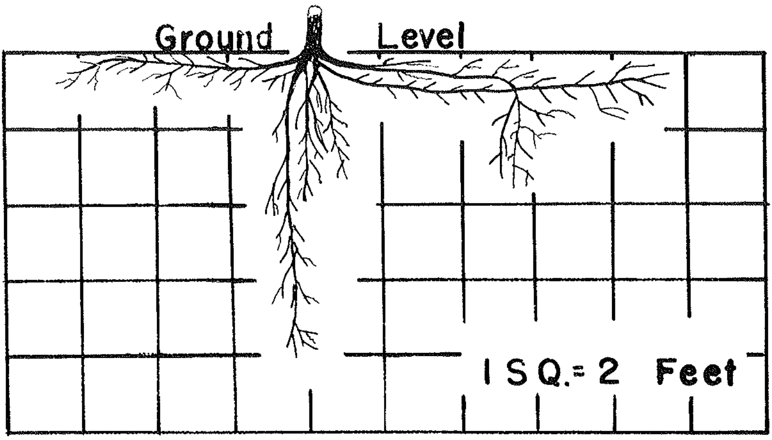


Fig. 13. Black locust: 12 years, 27 feet tall, water table 16 feet, Cass silty clay loam, Dakota County. Black locust, like honeylocust, has good drought-resistance. The relatively deep root system at 8 feet for this young sapling undoubtedly enables black locust to survive on dry sites.

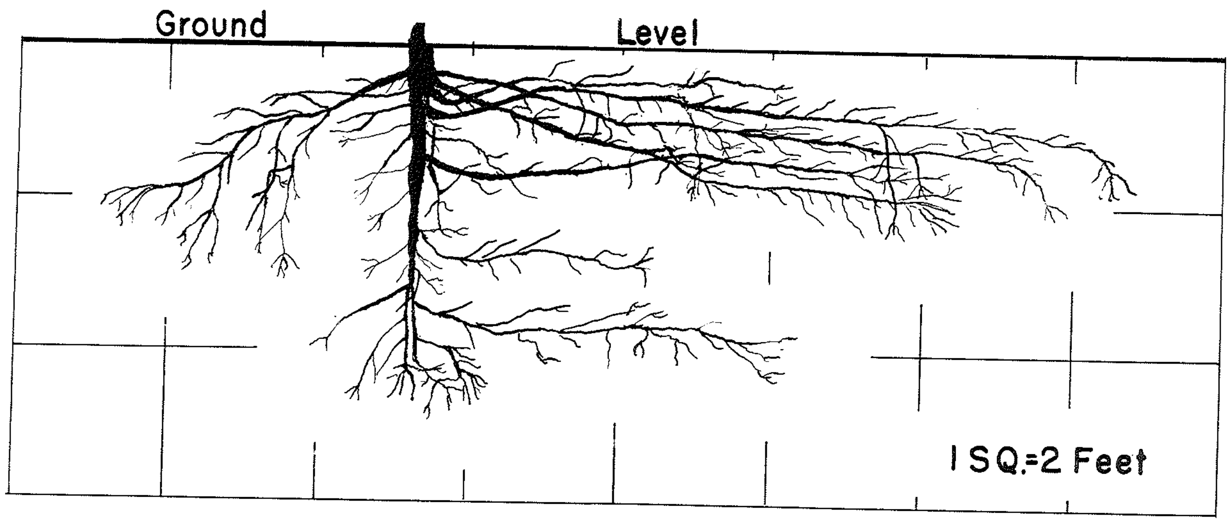


Fig. 14. Osage-orange: 3 years, 7 feet tall, water table 20 feet, Wabash silt loam, Lancaster County. A well developed taproot is characteristic of Osage-orange at early age.

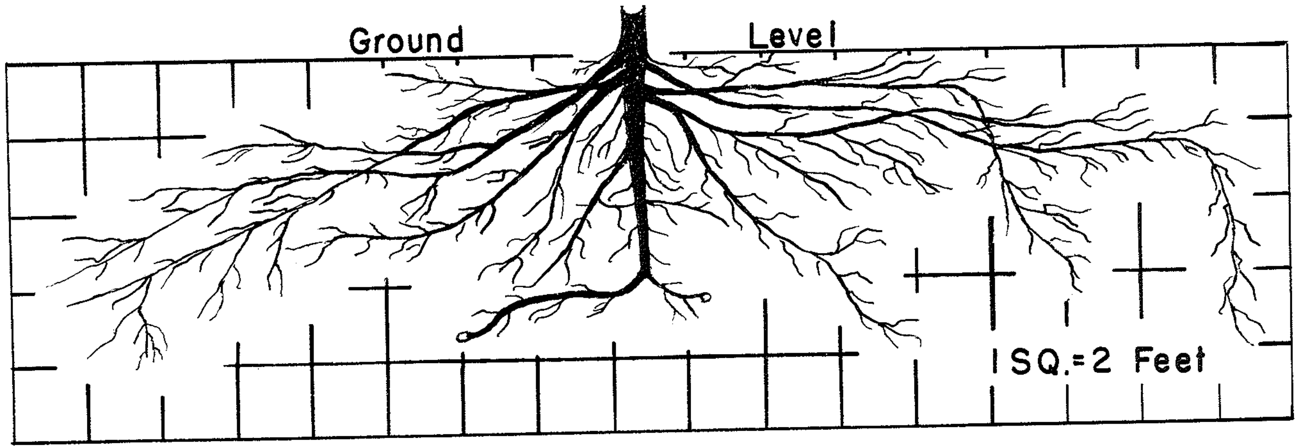


Fig. 15. Osage-orange: 23 years, 16 feet tall, water table 65 feet, Sogn silty clay loam, Pawnee County. This species is well known for drought-resistance. In addition to a strong taproot, the lateral root system is extensive throughout soil depths to 8 feet.

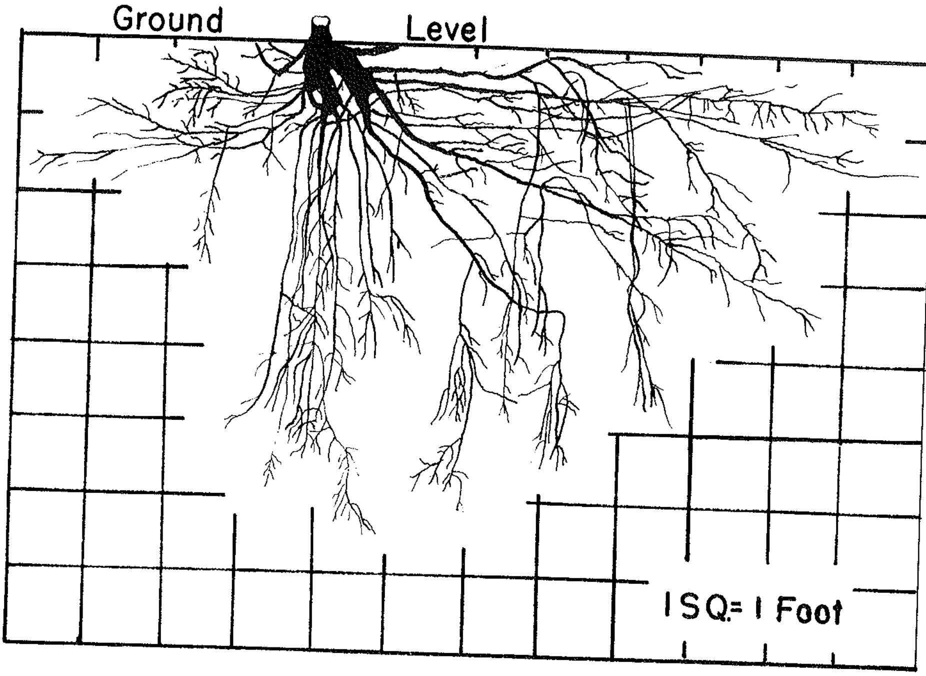


Fig. 16. Russian-olive: 3 years, 8 feet tall, water table 20 feet, Wabash silt loam, Lancaster County. Drought-resistance characterizes this introduced species, which was commonly planted in windbreaks during the 1930s. This 3-year-old seedling had a well developed root system penetrating to 7 feet.

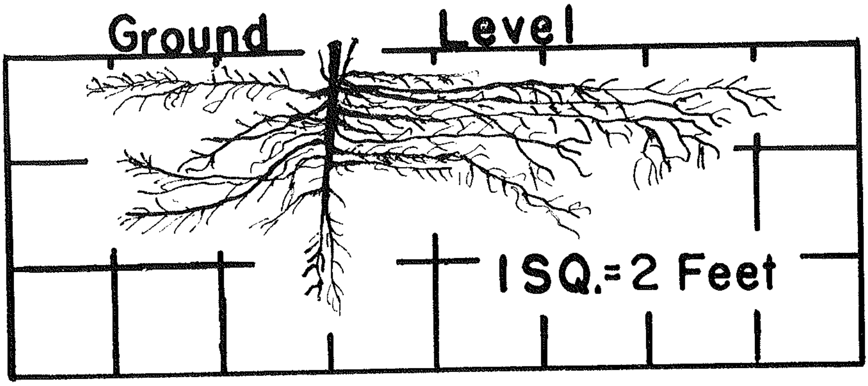


Fig. 17. Hawthorn: 19 years, 6 feet tall, water table 22 feet, Carrington silt loam, Pawnee County. Roots of this tree were deep in relation to its height (d/h = 0.75); this characteristic may be partially responsible for the successful invasion of dry pasturelands by the species.

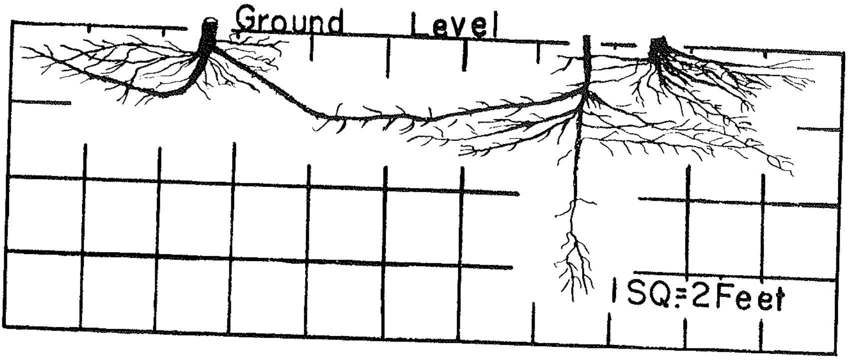


Fig. 18. Smooth sumac: 9 years, 9 feet tall, water table 81 feet, Bartlett silty clay loam, Pawnee County. Smooth sumac reproduces vegetatively from root suckers, illustrated above. Consequently, patches (clones) of sumac can be found growing in old fields or along railroad tracks in Nebraska.

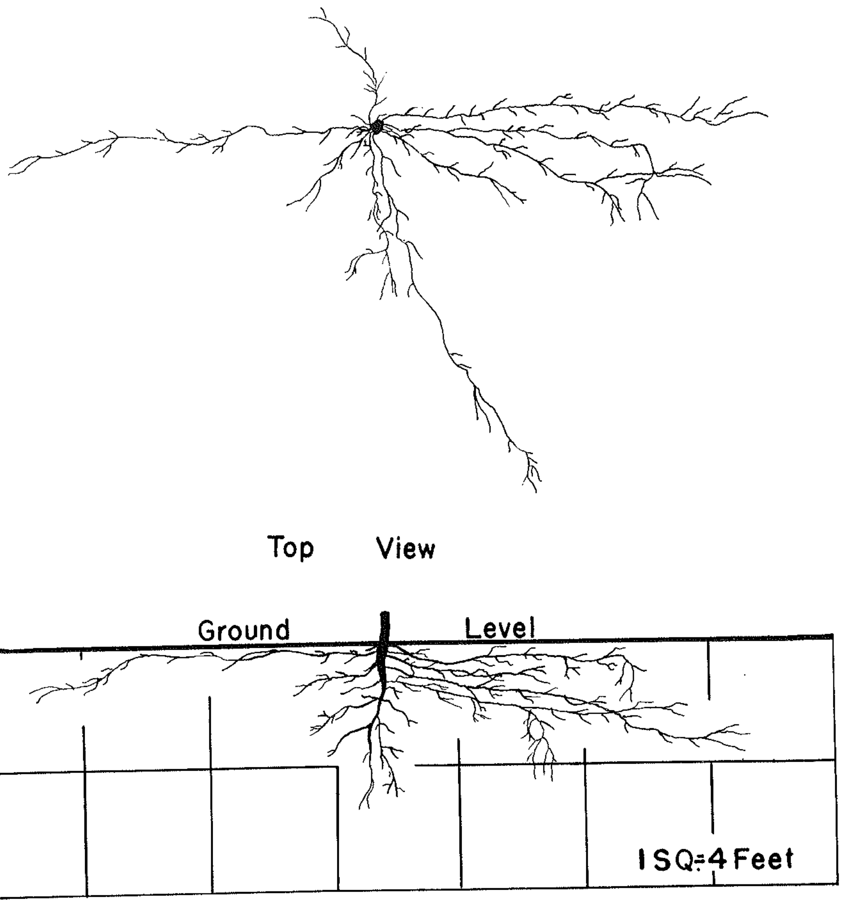


Fig. 19. Black walnut: 7 years, 5 feet tall, water table 20 feet, Wabash silt loam, Lancaster County. This species is well known for developing a strong taproot system, followed by wide-spreading lateral roots.

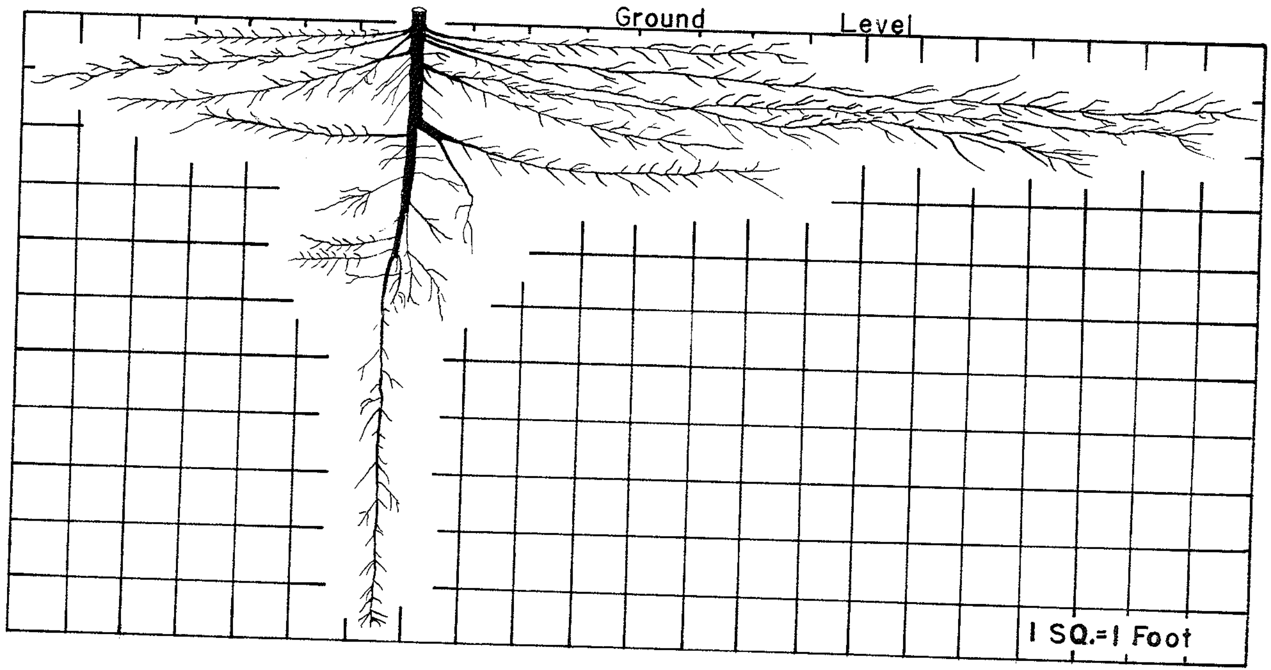


Fig. 20. Black walnut: 15 years, 15 feet tall, water table 14 feet, Cass silty clay loam, Dakota County. Although this species grows best on moist bottomlands, it has fair drought-resistance by virtue of its deep taproot, especially when planted on dry upland sites.

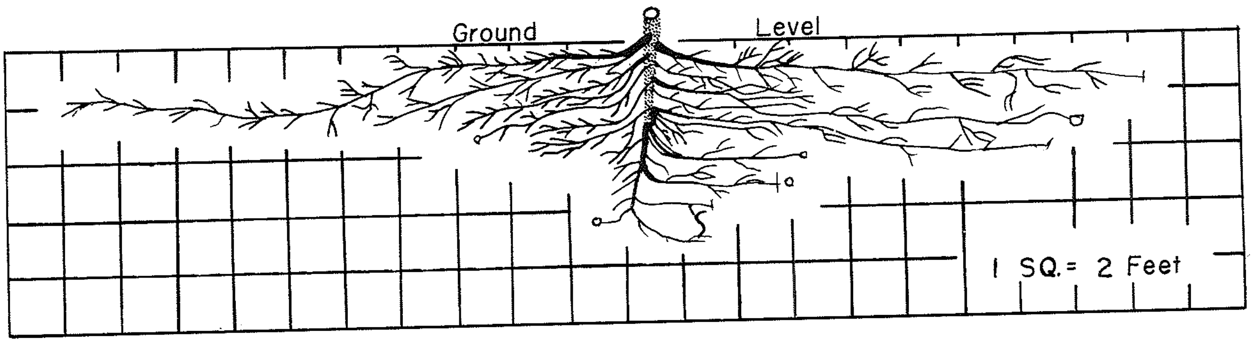


Fig. 21. Shagbark hickory: 40 years, 39 feet tall, water table 70 feet, Knox silt loam, Richardson County. This species, which grows only in extreme eastern Nebraska on deep, moist soils, developed a strong taproot early in life, followed by lateral root growth.

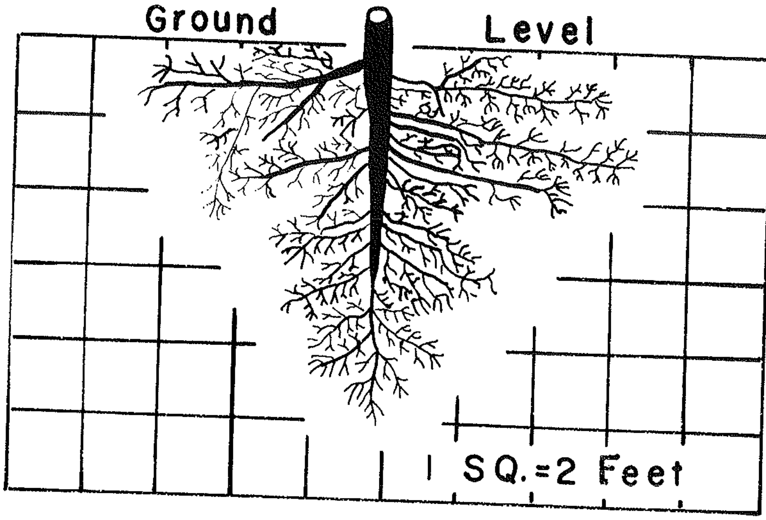


Fig. 22. Bitternut hickory: 28 years, 39 feet tall, water table 20 feet, Wabash silt loam, Pawnee County. A very strong taproot characterized the root system of this species. The root systems and site requirements of hickories are very similar to those of the walnut.

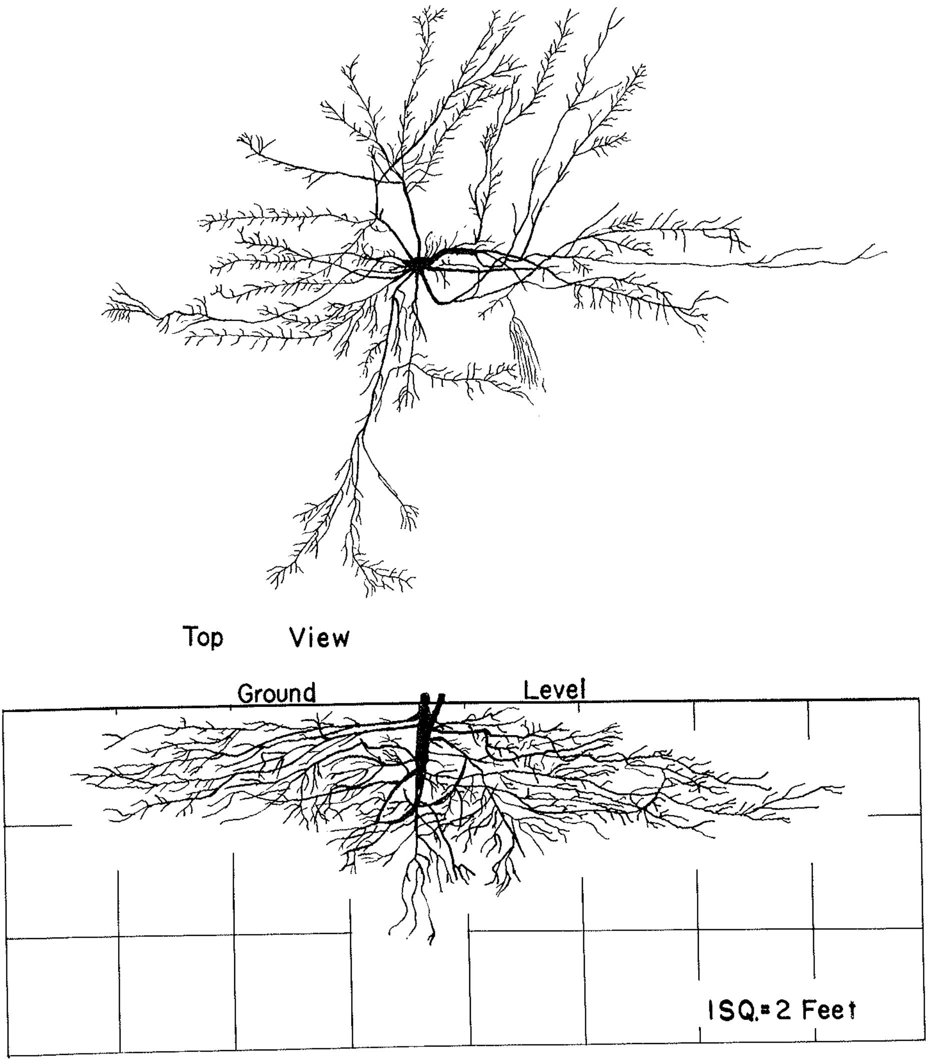


Fig. 23. Red mulberry: 7 years, 12 feet tall, water table 16 feet, Wabash silt loam, Lancaster County. Native only in southeastern Nebraska, this sapling mulberry had medium root depth and a fine network of lateral roots.

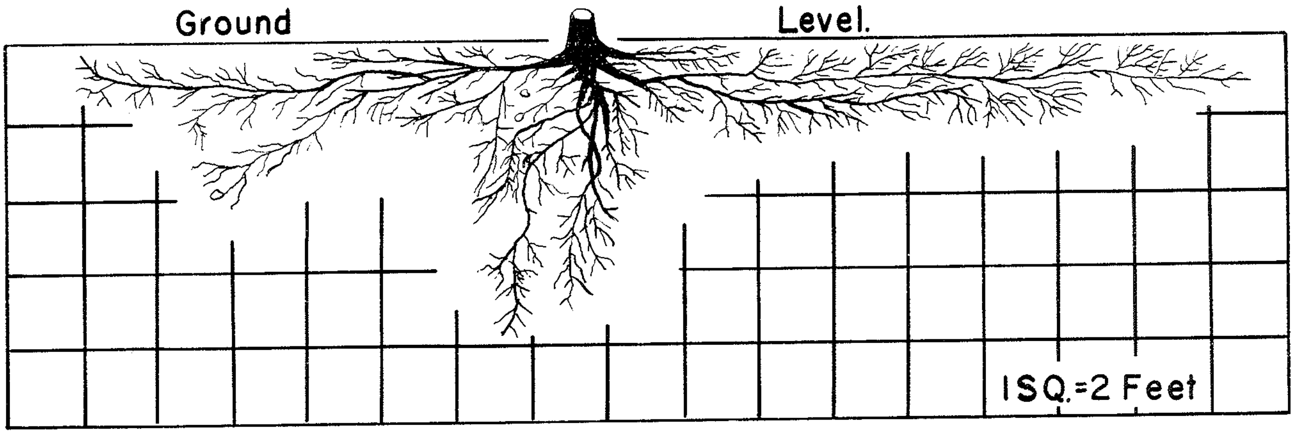


Fig. 24. Red mulberry: 21 years, 26 feet tall, water table 20 feet, Wabash silt loam, Pawnee County. No distinct taproot has developed, but a well developed network of fine lateral roots is apparent.

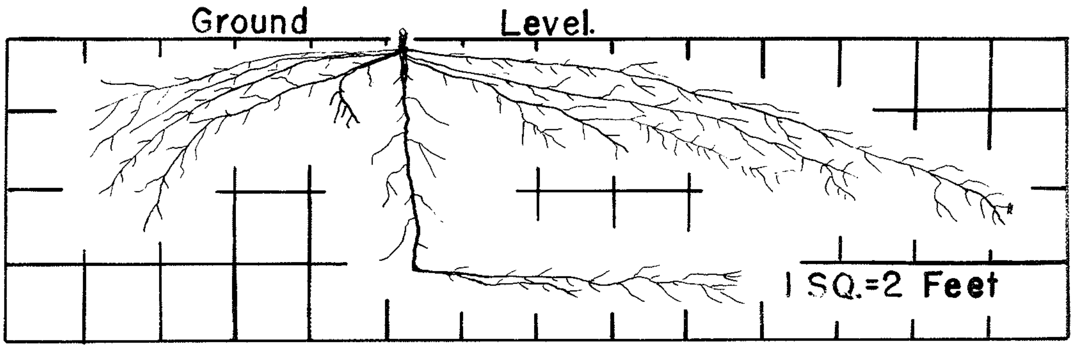


Fig. 25. Russian mulberry: 3 years, 4.5 feet tall, water table 11 feet, Cass sandy loam, Merrick County. Introduced into the United States by Russian Mennonites in 1875, this species has a root system similar to the native red mulberry. In this instance, the occurrence of coarse gravel beneath the subsoil at a depth of 5 feet has caused the taproot to turn and grow laterally.

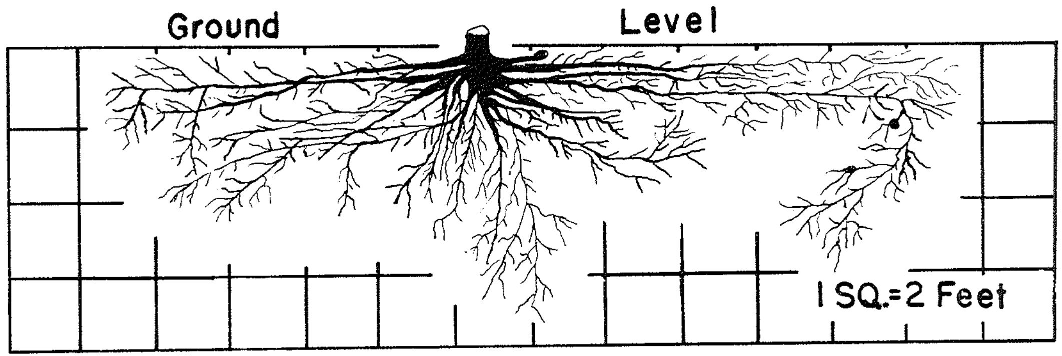


Fig. 26. Russian mulberry: 21 years, 14 feet tall, water table 50 feet, Pawnee silty clay loam, Pawnee County. This sapling mulberry has an exceptionally well developed root system for drought-resistance.

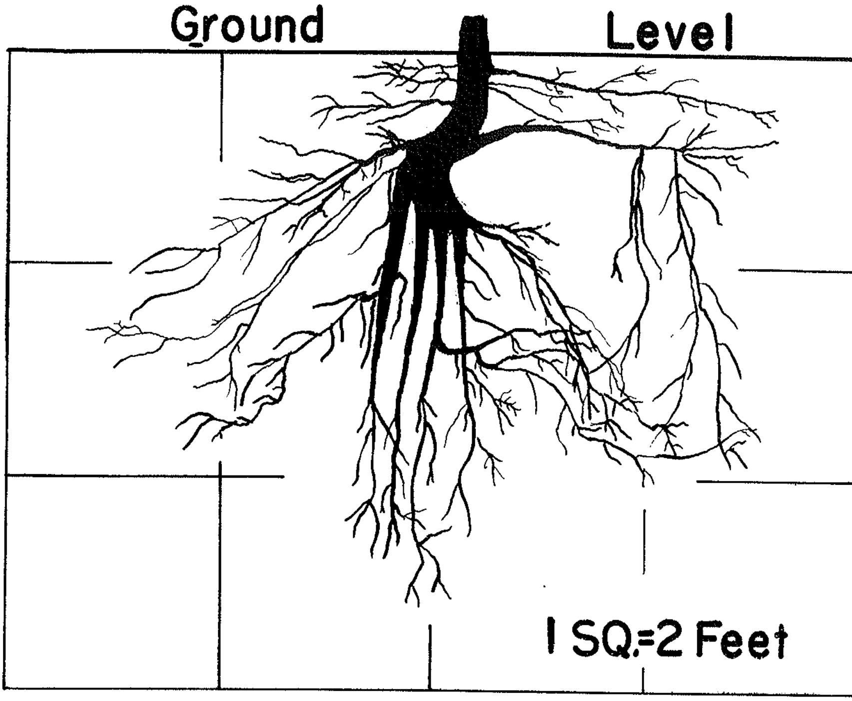


Fig. 27. Plains cottonwood: 3 years, 5 feet tall, water table 21 feet, Wabash silt loam, Lancaster County. This bottomland native of the prairie extended roots in all directions. Cottonwoods, with a standard deviation of 0.52, showed the widest variation of all species in root depth/height ratio (see table 2).

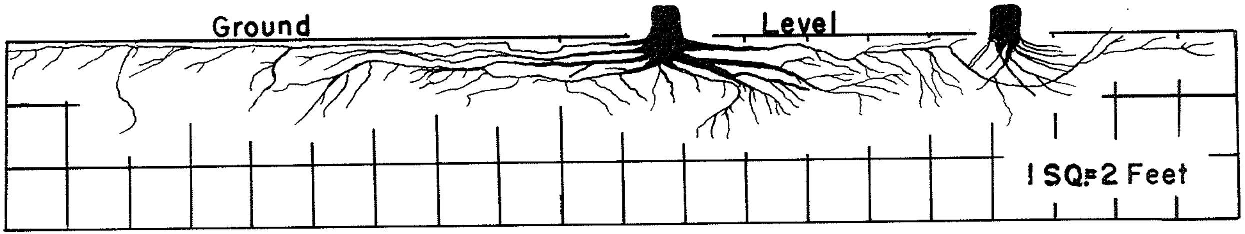


Fig. 28. Plains cottonwood: 14 years, 60 feet tall, water table 2.5 feet, Cass loam, Nance County. In this instance, a tree 60 feet high has roots only 2.5 feet deep. A water table very close to the surface created a saturated subsoil, restricting root aeration. Only shallow widespread roots could survive (d/s = 0.06, in comparison to species average of 0.39).

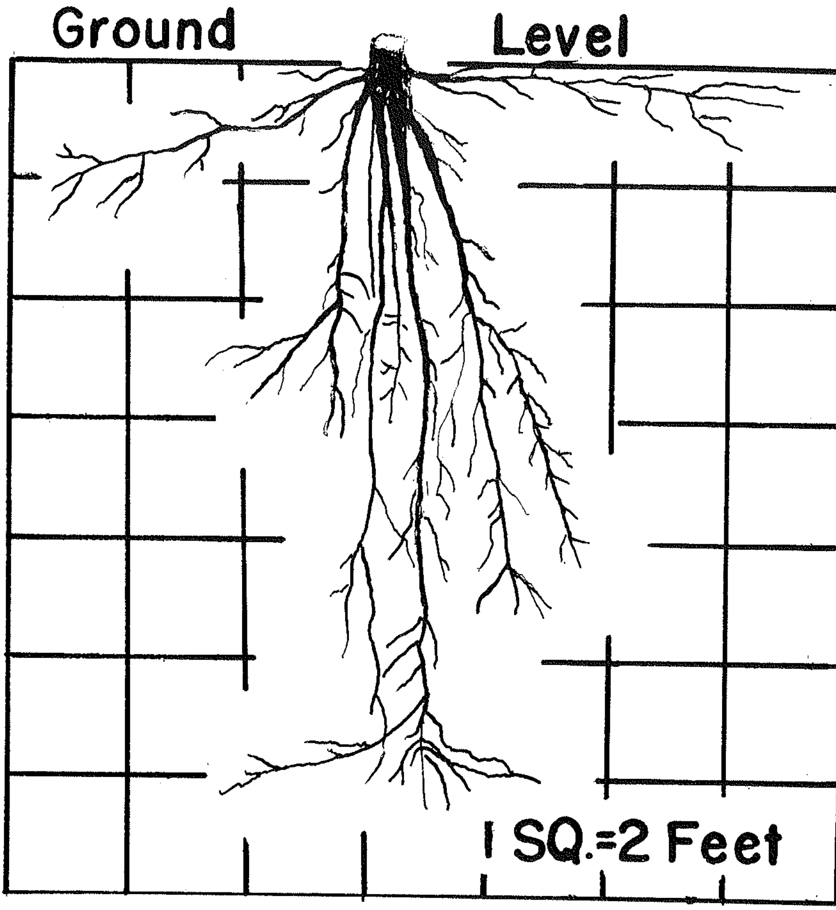


Fig. 29. Plains cottonwood: 16 years, 37 feet tall, water table 14 feet, Cass silty clay loam, Dakota County. Roots of this tree have grown downward to 12 feet, just above the water table level, and then branched laterally.

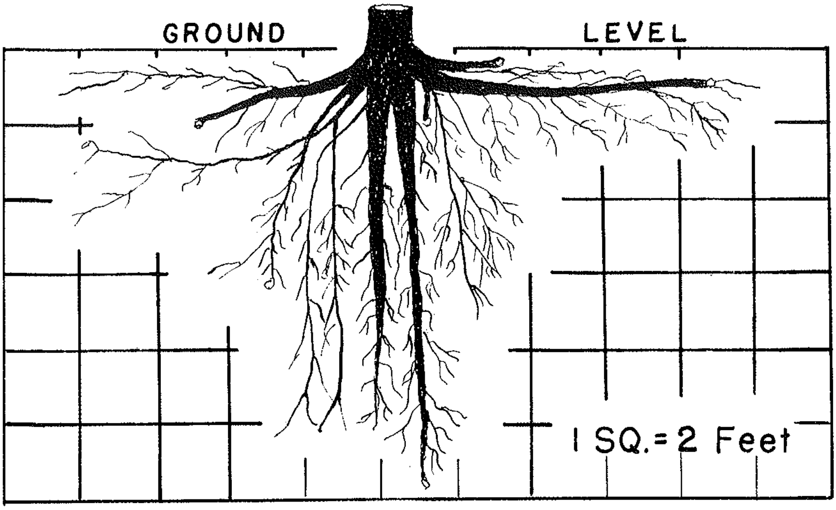


Fig. 30. Plains cottonwood: 49 years, 70 feet tall, water table 60 feet, Marshall silt loam, Dakota County. Roots of this older cottonwood, on an upland site where the water table is out of reach, have a distinct taproot pattern, in contrast with the pattern shown in figure 28.

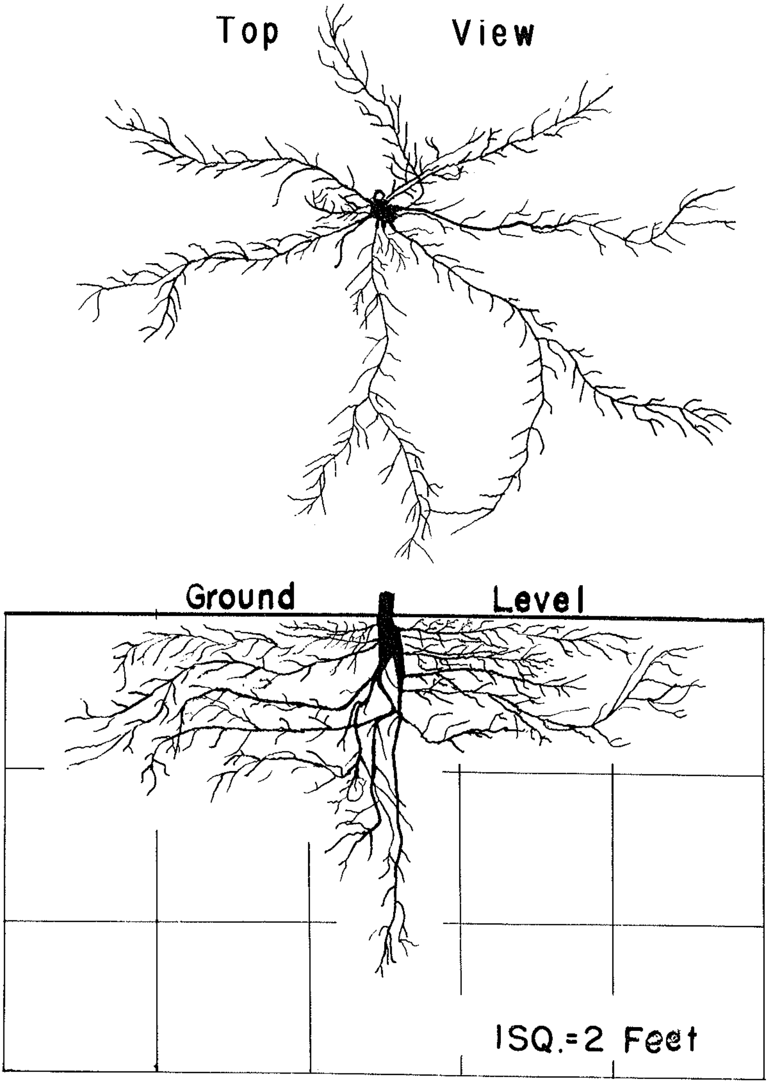


Fig. 31. Green ash: 3 years, 4 feet tall, water table 22 feet, Wabash silt loam, Lancaster County. Green ash is fairly drought-resistant. This seedling quickly extended roots downward to 5 feet and grew laterally in perfect symmetry.

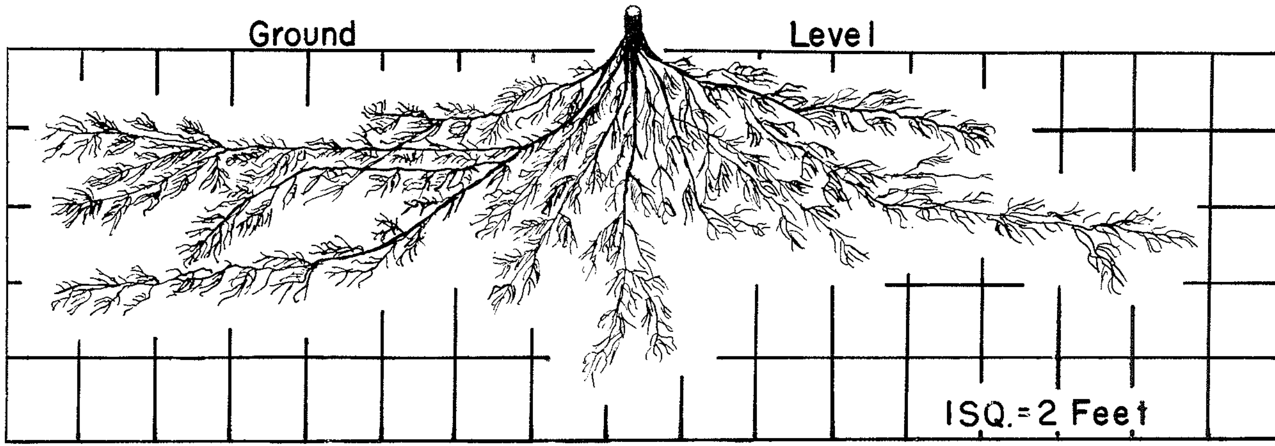


Fig. 32. Green ash: 24 years, 19 feet tall, water table 28 feet, Carrington silty clay loam, Pawnee County. A fine network of lateral roots of medium depth characterizes green ash.

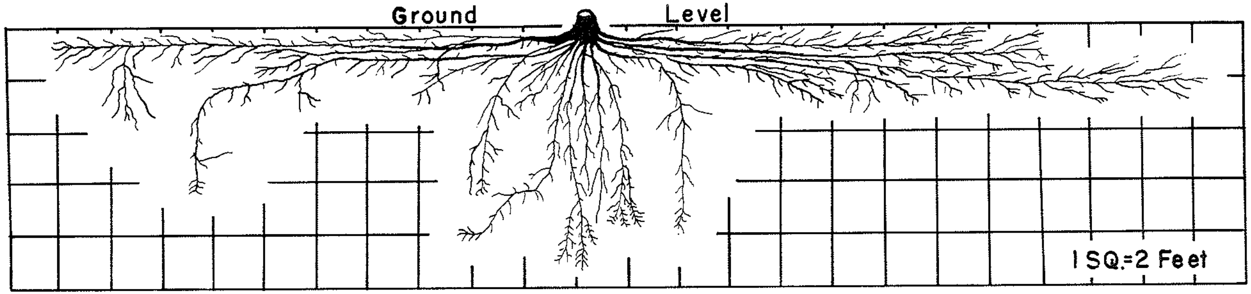


Fig. 33. Green ash: 45 years, 32 feet tall, water table 10 feet, Cass loamy sand, Merrick County. Roots penetrated to 9 feet, the same depth as the 25-year-old green ash in figure 32, but greater lateral spread is evident in this older tree.

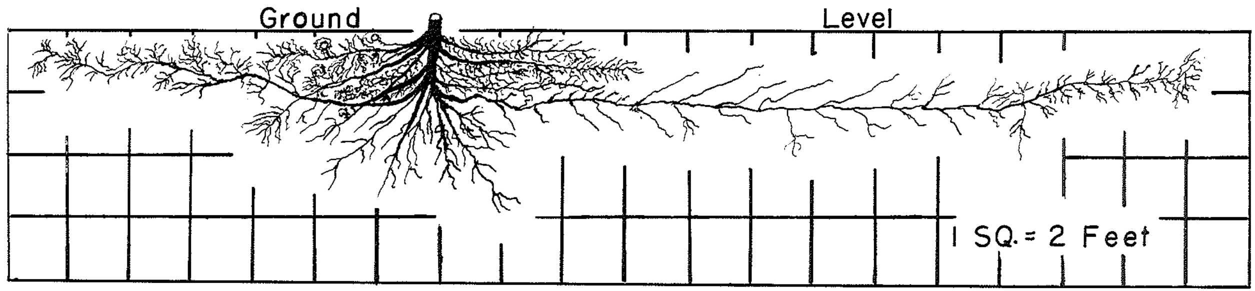


Fig. 34. White ash: 18 years, 28 feet tall, water table 70 feet, Knox silt loam, Richardson County. The root system of white ash, a native of upland sites along the Missouri River in eastern Nebraska, resembles green ash but is not as drought-resistant.

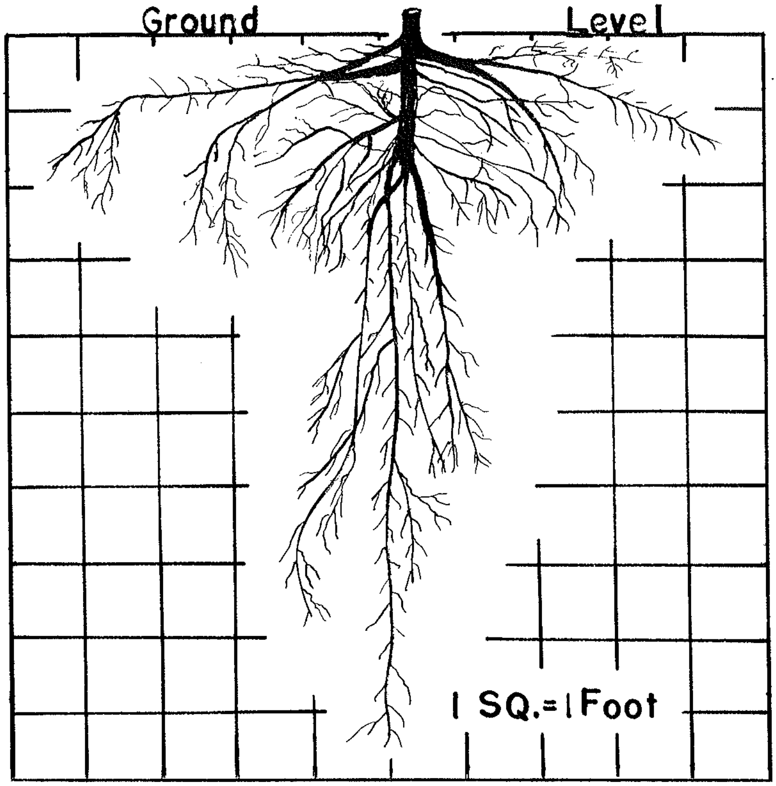


Fig. 35. Siberian elm: 10 years, 18 feet tall, water table 12 feet, Cass silty clay loam, Dakota County. A fast-growing introduction from eastern Asia, Siberian elm is well adapted to a windy, droughty environment. Only a few other broadleaf species are so adapted.

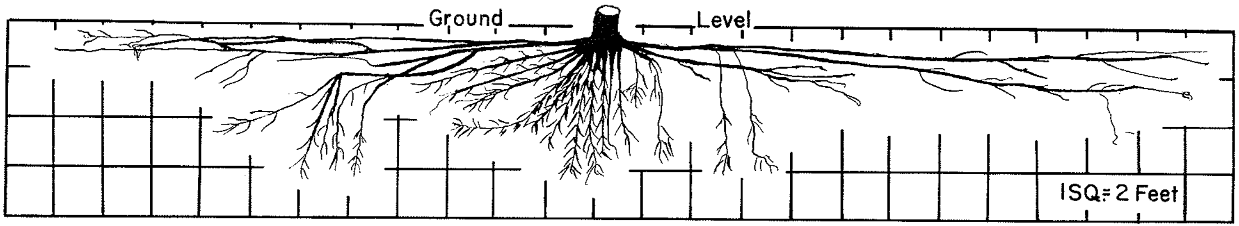


Fig. 36. Siberian elm: 9 years, 30 feet tall, water table 6.5 feet, Cass sandy loam, Merrick County. The high water table typically results in a shallow but very wide-spreading root system. The rate of lateral growth was nearly 3 feet a year.

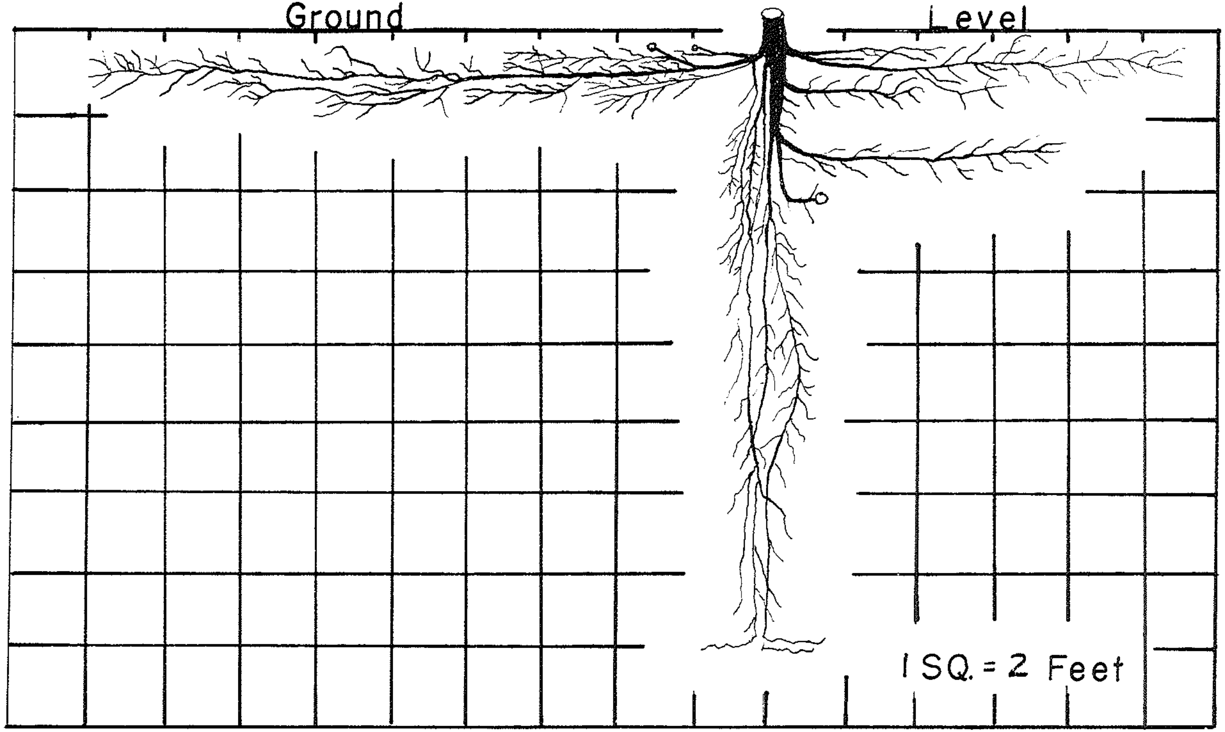


Fig. 37. Siberian elm: 11 years, 29 feet tall, water table 16 feet, Sarpy very fine sandy loam, Dakota County. Roots penetrated directly to the water table at 16 feet; lateral development was limited mostly to the surface 2 feet of soil.

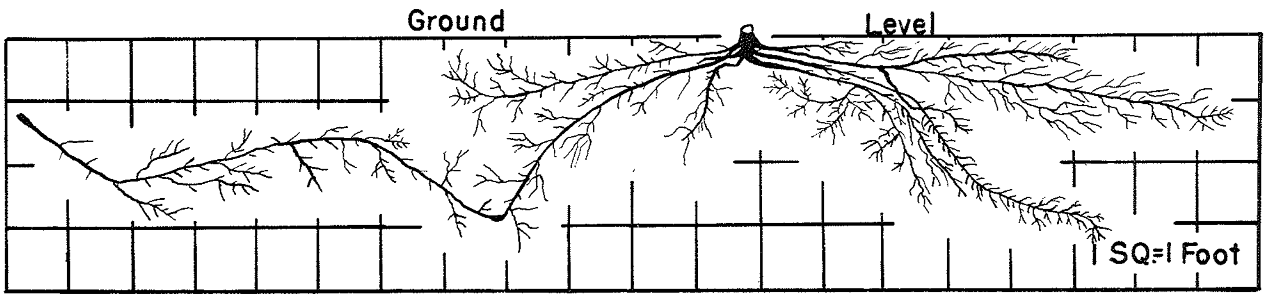


Fig. 38. Kentucky coffeetree: 6 years, 7 feet tall, water table 12 feet, Wabash silt loam, Pawnee County. A native of eastern Nebraska, this species is characterized by fairly slow growth and moderate drought-resistance. Note the root graft with an adjacent tree.

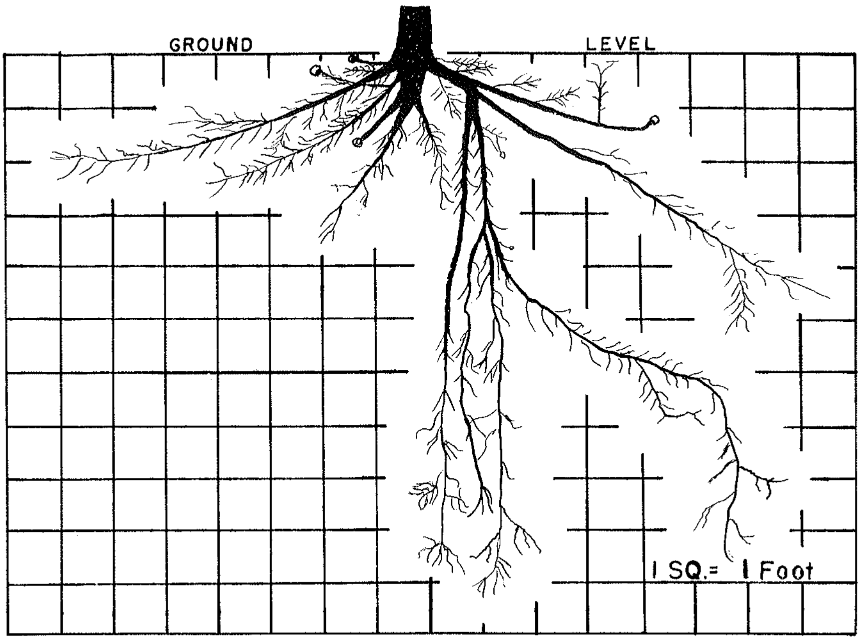


Fig. 39. Northern catalpa: 30 years, 38 feet tall, water table 20 feet, Sarpy very fine sandy loam, Dakota County. Catalpa was introduced in Nebraska from the southern states as a commercial fence post species, primarily because of its fast growth and resistant heartwood. The root system is as deep as it is wide.

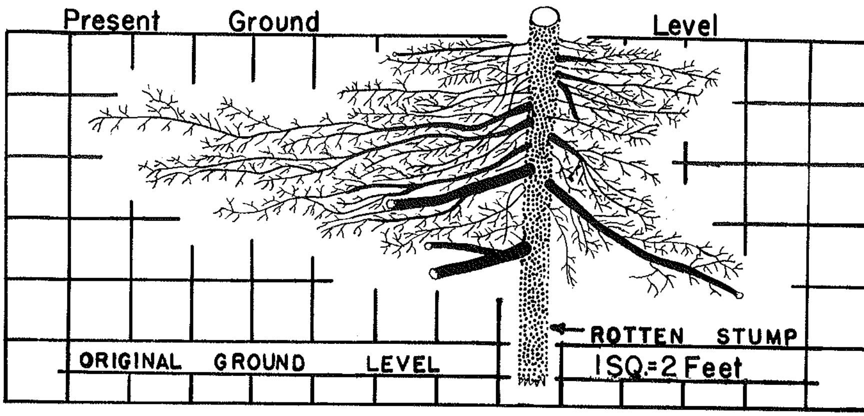


Fig. 40. American sycamore: 60 years, 68 feet tall, water table 20 feet, Wabash silt loam, Pawnee County. The tree shown here was growing in a swamp that had filled with alluvium. Ground level when excavated was 11 feet above the ground on which the seed had germinated. Lateral roots had developed on what was originally the lower portion of the tree stem.

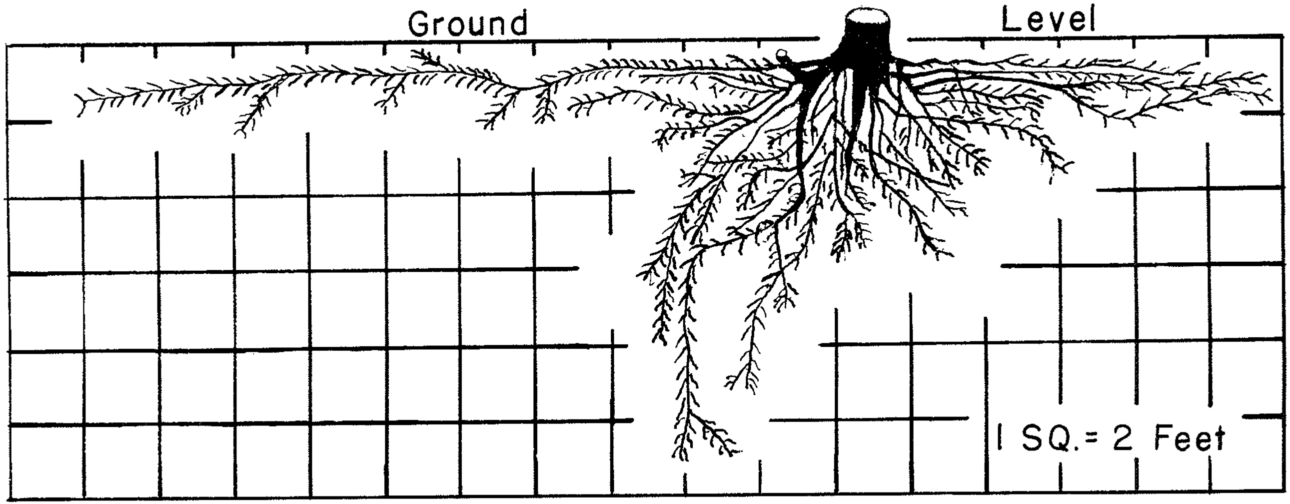


Fig. 41. Silver maple: 31 years, 40 feet tall, water table 12 feet, Wabash silt loam, Pawnee County. A fast-growing, shallow-rooted native species that prefers bottomland sites, silver maple also grows well when planted as an ornamental on drier sites.

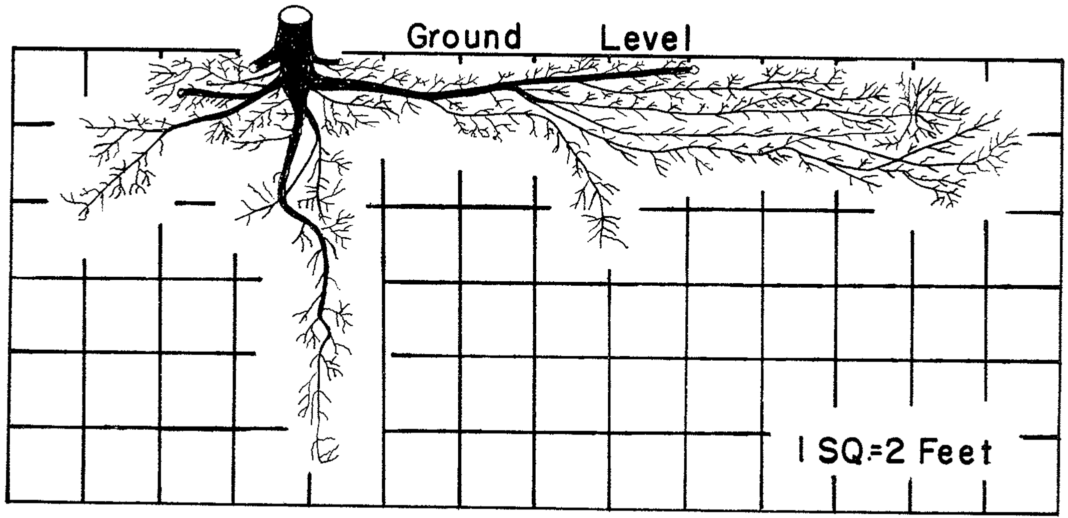


Fig. 42. Apple: 28 years, 18 feet tall, water table 55 feet, Butler silt loam, Pawnee County. Growing on a dry upland site, this apple tree had relatively deep roots.

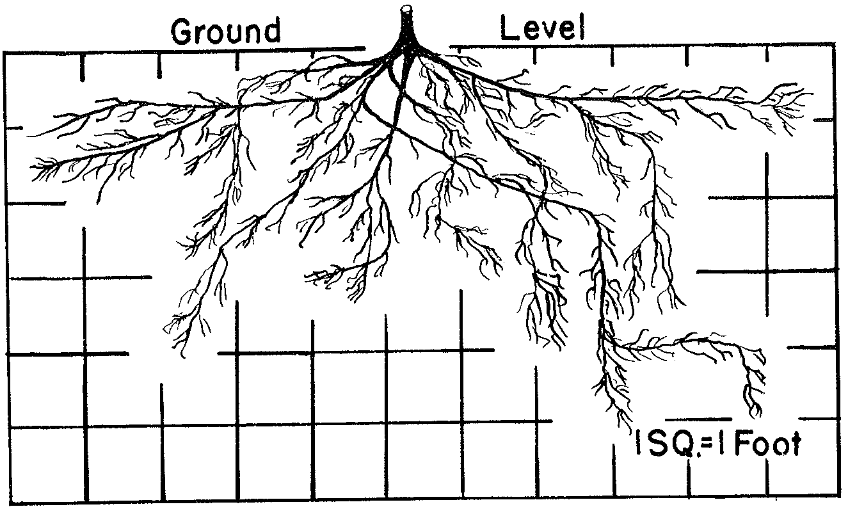


Fig. 43. Prickly-ash: 14 years, 5 feet tall, water table 81 feet, Sogn stony loam, Pawnee County. The above illustration represents a deep and widespread root system for such a small tree.

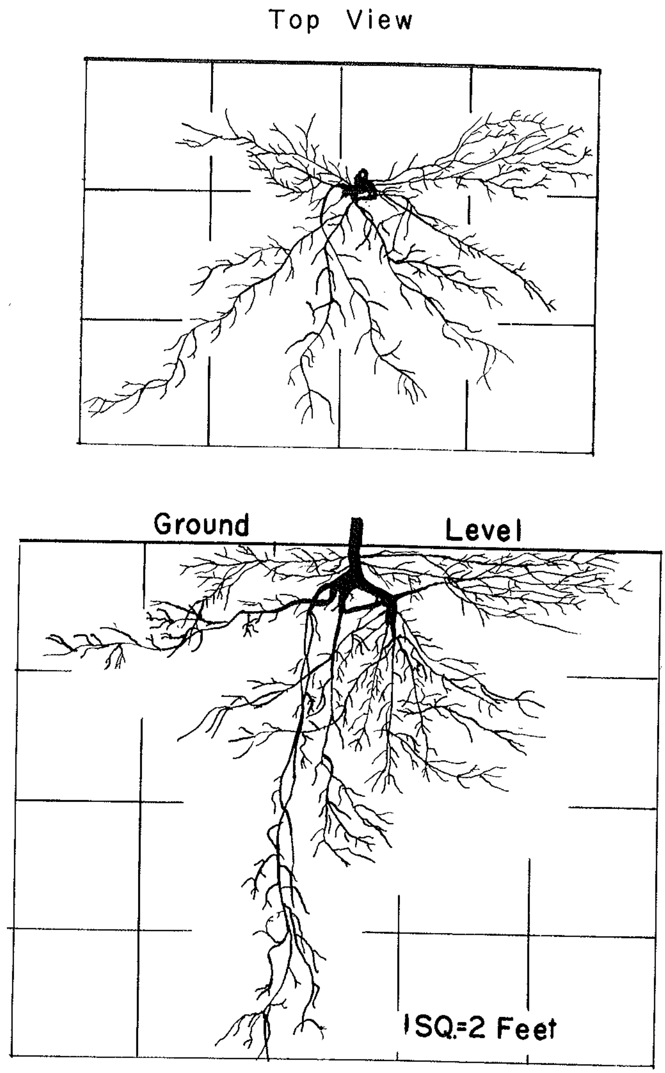


Fig. 44. American elm: 3 years, 10 feet tall, water table 21 feet, Wabash silty loam, Lancaster County. The taproot of this rapidly growing elm seedling penetrated to 8 feet in only 3 years.

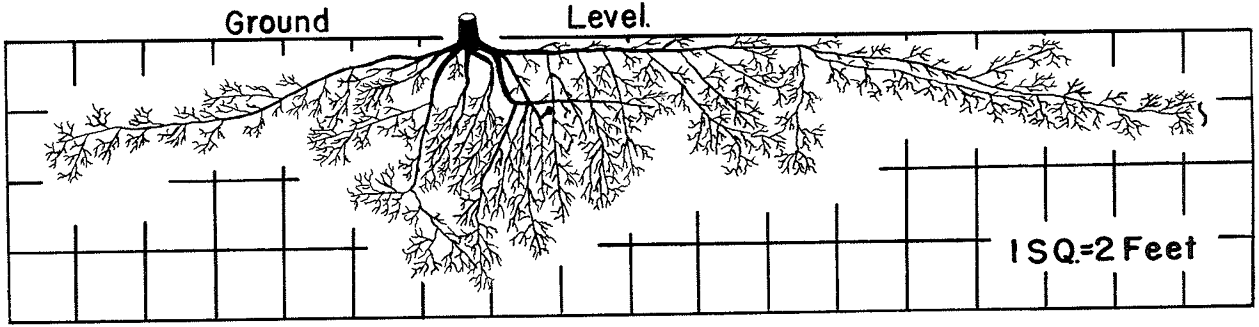


Fig. 45. American elm: 30 years, 28 feet tall, water table 8 feet, Cass sandy loam, Merrick County. This tree was growing on bottomland with the water table fairly close to the surface. The root system is shallow but wide-spreading.

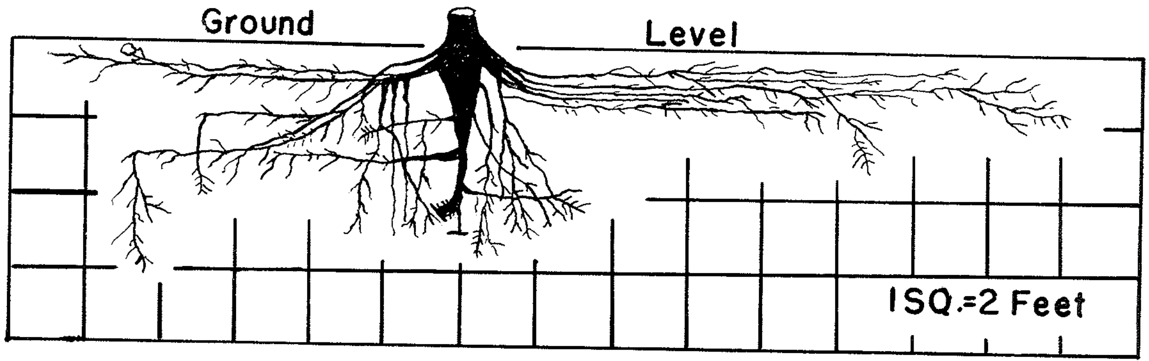


Fig. 46. American elm: 58 years, 55 feet tall, water table 30 feet, Wabash silt loam, Richardson County. This tree had a well defined taproot system, which was fairly shallow for a tree of this age.

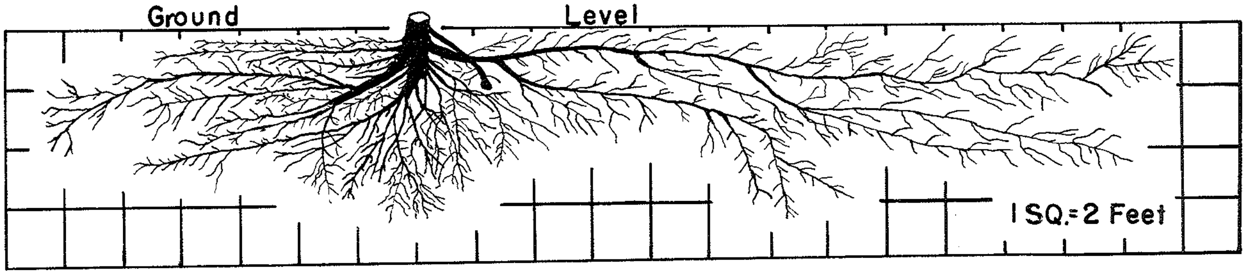
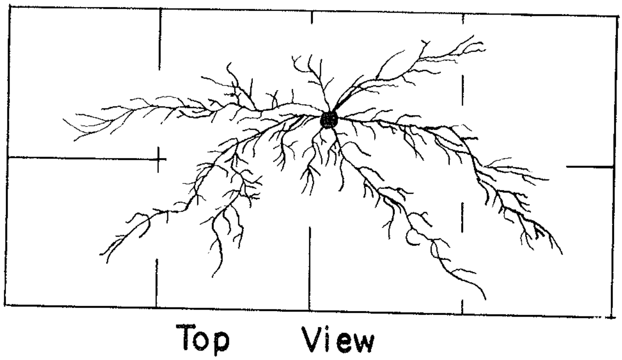


Fig. 47. Slippery elm: 67 years, 35 feet tall, water table 14 feet, Wabash silt loam, Pawnee County. Preferring bottomland sites, this slippery (red) elm developed a strong lateral root system similar to the American elm represented in figure 45.



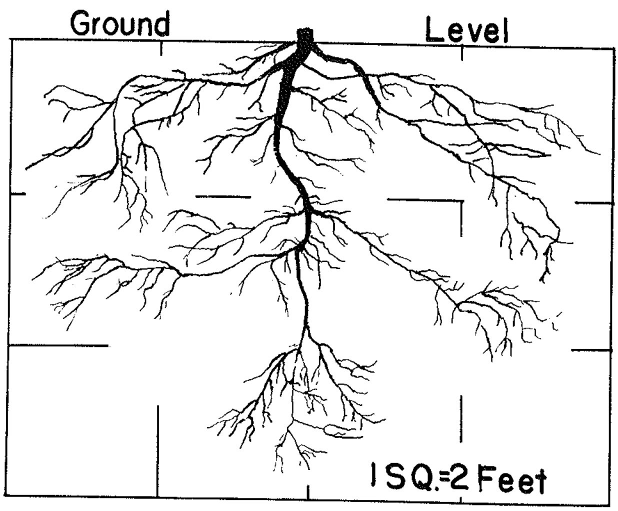


Fig. 48. Boxelder: 7 years, 8 feet tall, water table 14 feet, Wabash silty clay loam, Lancaster County. Roots of this sapling grew about a foot a year in depth, extending a well-branched lateral system throughout the top 4 feet of soil.

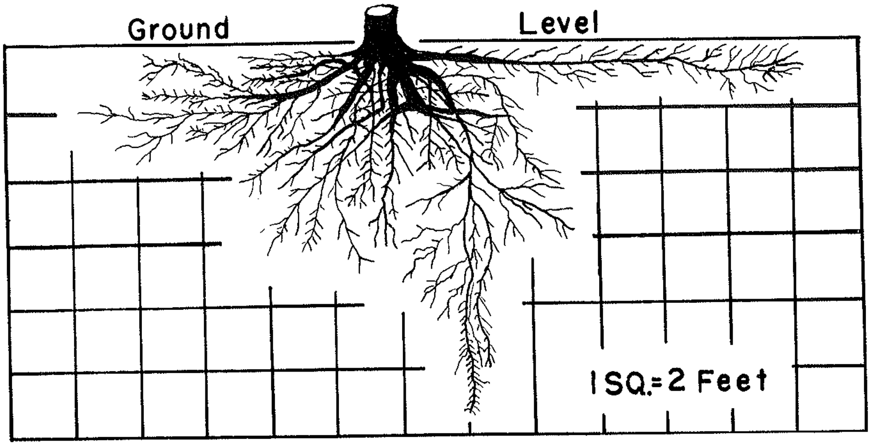


Fig. 49. Boxelder: 34 years, 33 feet tall, water table 14.5 feet, Wabash silt loam, Pawnee County. Growing on bottomland, this tree had a dense network of lateral roots but lacked a strong taproot system.

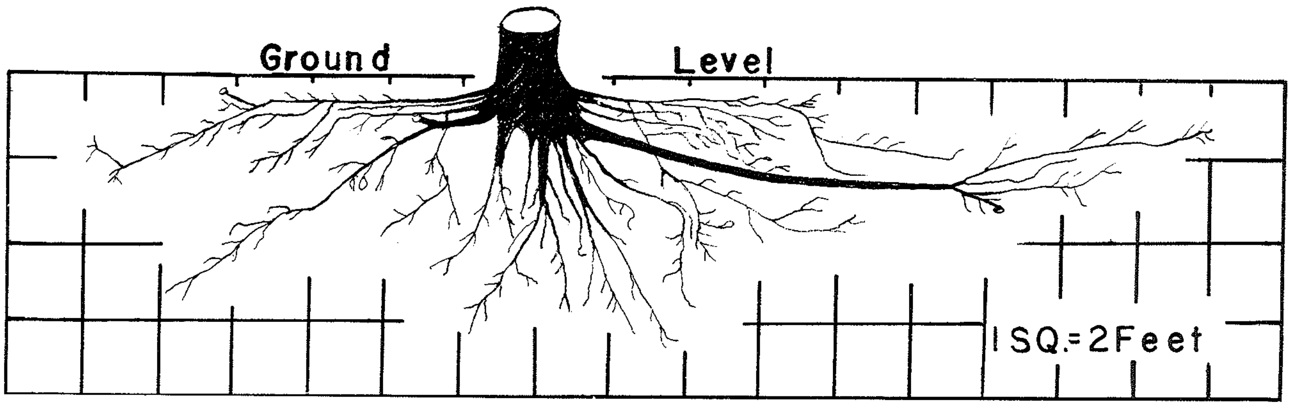


Fig. 50. Boxelder: 54 years, 40 feet tall, water table 19 feet, Wabash clay, Dakota County. This species has a fairly sparse lateral system in relation to tree size. Boxelder has no taproot and is not especially drought-resistant.

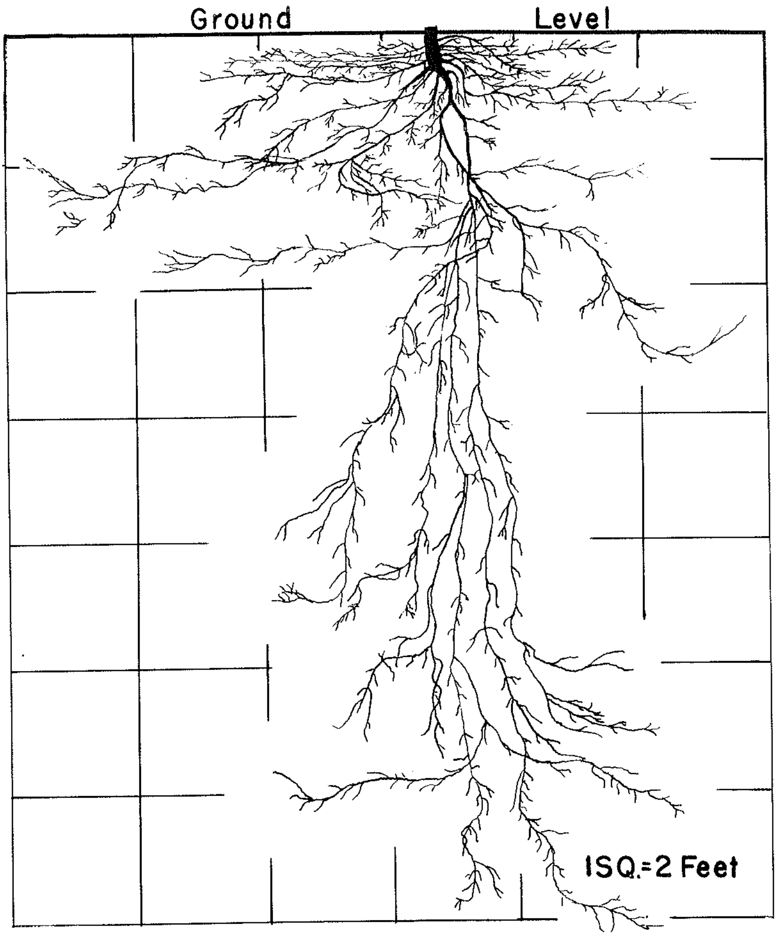


Fig. 51. Peachleaf willow: 4 years, 15 feet tall, water table 16 feet, Wabash silt loam, Lancaster County. Growing on a stream bank 8 feet above the creek bed, this willow probably exceeds all other species in rate of root penetration. The root system reached a depth of 14 feet in 4 years and was only 12 feet wide (d/s = 1.19).

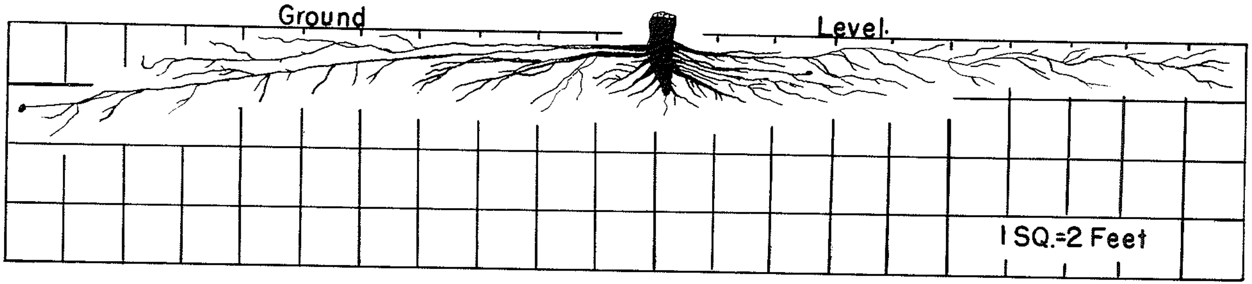


Fig. 52. Peachleaf willow: 16 years, 48 feet tall, water table 2.5 feet, Cass fine sandy loam, Nance County. A comparison of this root system with that in figure 51 shows its relative plasticity as influenced by the depth of the water table. The willow shown here was growing on a bottomland site with the water table 2.5 feet below soil surface. The root system was 44 feet wide and 2.5 feet deep (d/s = 0.06).

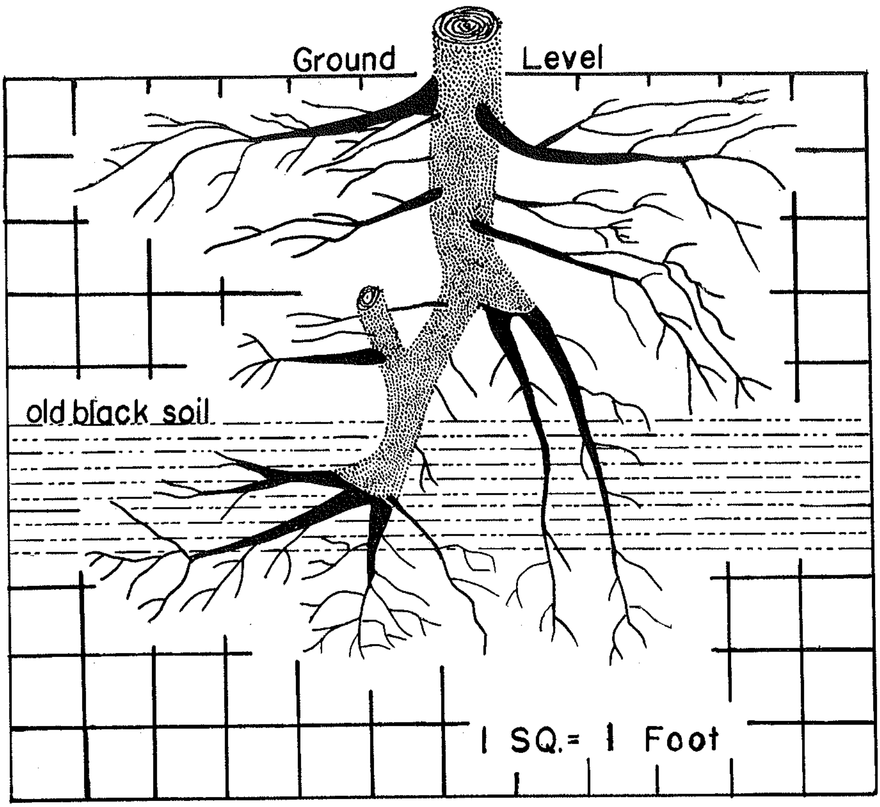


Fig. 53. Black willow: 28 years, 42 feet tall, water table 8 feet, Cass loamy sand, Nance County. This willow growing along a stream bottom survived the gradual deposition of 5 feet of alluvium over a 28-year-period. Lateral roots developed from the lower stem after it was buried.

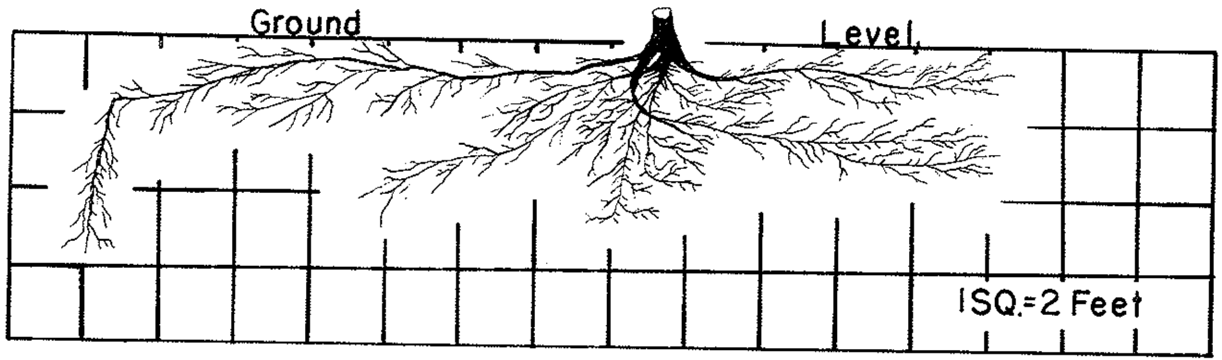


Fig. 54. Redbud: 20 years, 35 feet tall, water table 20 feet, Wabash silt loam, Pawnee County. A native of southeastern Nebraska woodlands and an understory tree on moist sites, this redbud had a network of fine lateral roots.

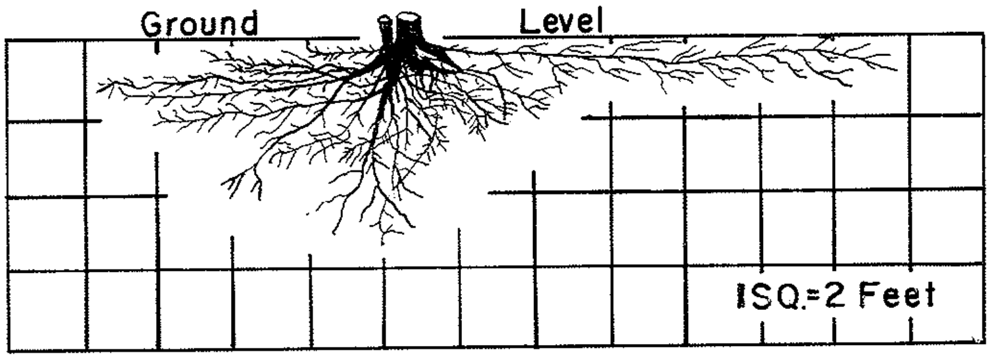


Fig. 55. American basswood: 40 years, 44 feet tall, water table 14 feet, Wabash silt loam, Pawnee County. Basswood commonly sprouts at the base, resulting in clumps of trees. The roots are mostly shallow and widespread.

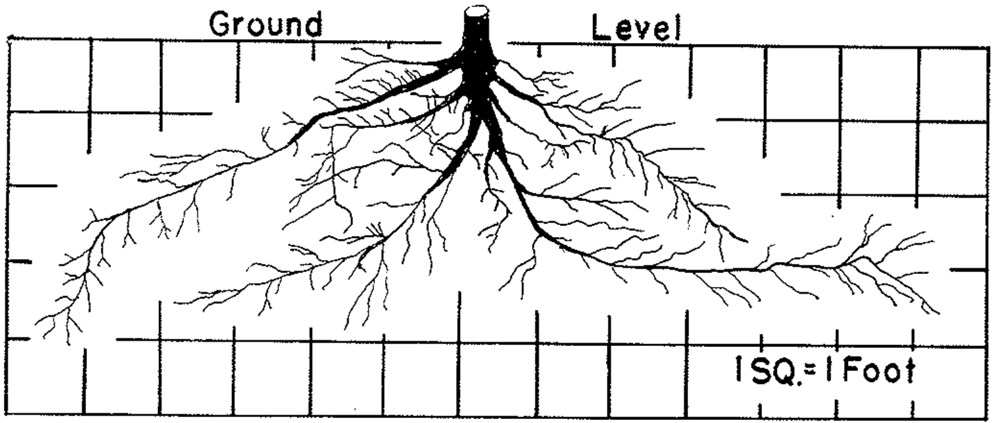


Fig. 56. Ohio buckeye: 19 years, 9 feet tall, water table 14 feet, Wabash silt loam, Pawnee County. This tree developed a short, forked taproot. The species grows in extreme southeastern Nebraska on moist sites only.

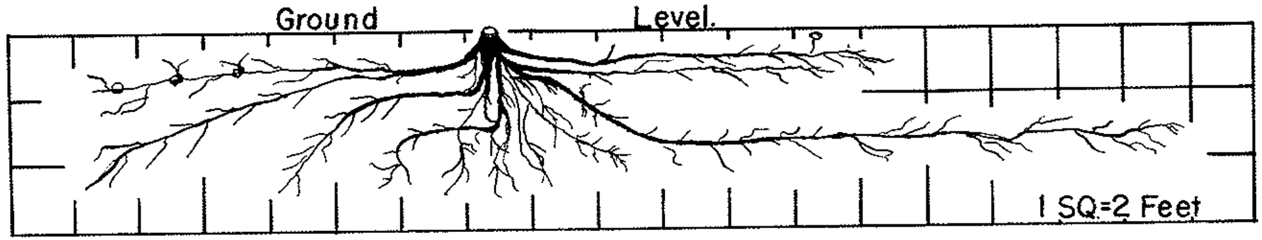


Fig. 57. American (wild) plum: 15 years, 12 feet tall, water table 8 feet, Cass sandy loam, Merrick County. Plum grows throughout Nebraska on moist sites beside roads, streams, and lakes. Its root system is shallow and widespread.

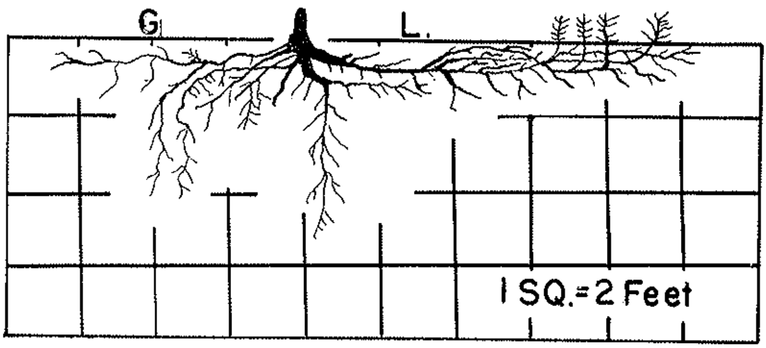


Fig. 58. Chokecherry: 20 years, 17 feet tall, water table 20 feet, Wabash silt loam, Richardson County. Roots of chokecherry, like those of American plum, are shallow and wide-spreading. Note the new plants originating from root suckers.

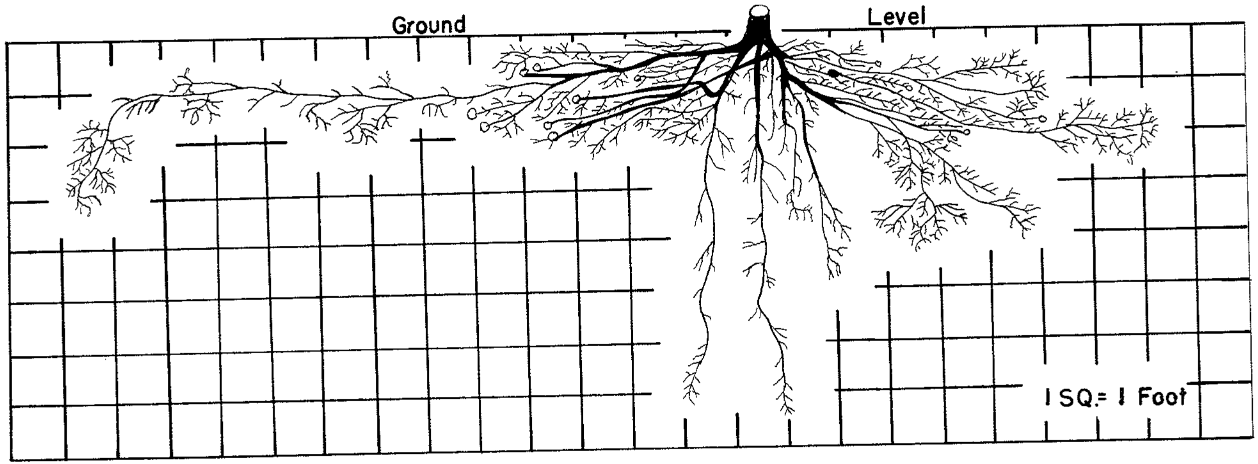


Fig. 59. Apricot: 12 years, 14 feet tall, water table 55 feet, Marshall (heavy subsoil phase), Pawnee County. Apricot was introduced to Nebraska for fruit production. This tree, located on a dry upland site, has the greatest mass of its roots in the upper 4 feet of soil.

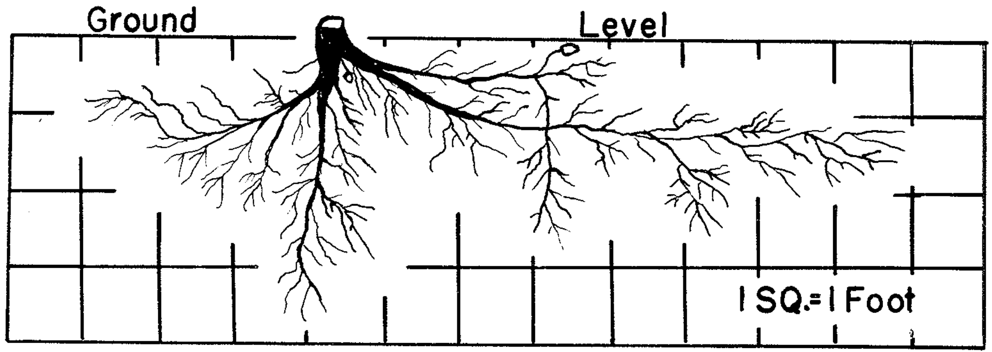


Fig. 60. Black cherry: 18 years, 22 feet tall, water table 70 feet, Knox silt loam, Richardson County. This species has about the same site requirements (moist bottomlands) and root structures as chokecherry (see figure 58).

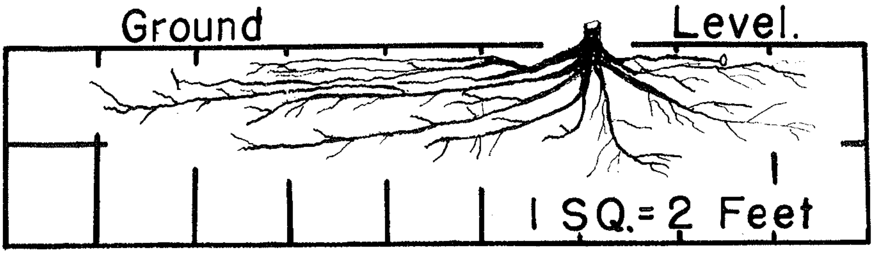


Fig. 61. Eastern hophornbeam: 35 years, 19 feet tall, water table 80 feet, Marshall silt loam, Dakota County. This native understory species of eastern Nebraska prefers moist sites and has a shallow root system.

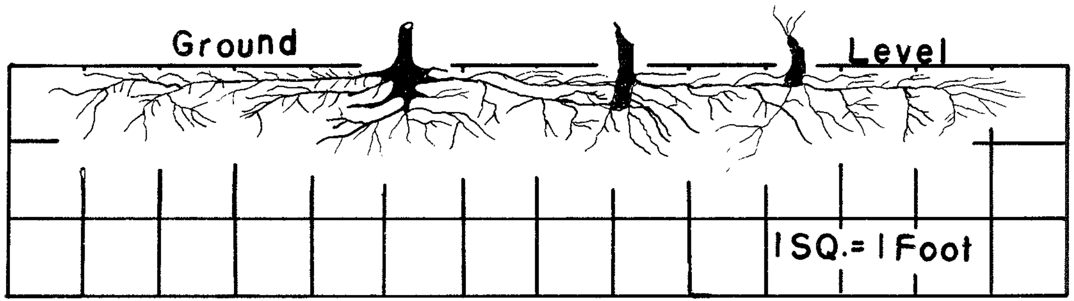


Fig. 62. Dogwood: 15 years, 18 feet tall, water table 4 feet, Cass fine sandy loam, Nance County. Dogwood, like sumac (see figure 18), reproduces vegetatively from roots. A high water table here resulted in very shallow roots.