Alnus glutinosa (L.) Gaertn. European Alder

Betulaceae **Birch family**

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European alder *(Alnus glutinosa)*, also called black alder or European black alder, was introduced to eastern North America in colonial times. This tree ranges in size from a large shrub to a large tree. It has escaped cultivation and grows naturally on low-lying lands. Its rapid growth, tolerance for acid soils, and nitrogen-fixing role make European alder desirable for shelterbelts, reclamation areas, landscapes, and biomass production. It is valuable to wildlife for providing good cover and a source of seeds.

Habitat

Native Range

European alder has a broad natural range that includes most of Europe and extends into North Africa, Asia Minor, and western Siberia (82). Densest distribution is in the lowlands of northern Germany, northern Poland, White Russia, and the northwestern Ukraine *(33)*. The species is locally naturalized throughout the northeastern United States and maritime Canada.

Climate

The duration of low winter temperature limits the range of European alder in Scandinavia because the species does not extend into regions where the mean daily temperature is above freezing for less than 6 months of the year. The southeastern boundary of European alder distribution in Eurasia corresponds closely with the 500 mm (20 in) annual rainfall line *(60)*. European alder is hardy to winter temperatures of -54” C (-65” F) *(36)*, but apparent winter damage to young European alder plantings in North Carolina resulted in partial to complete dieback of 80 percent of the trees. Relatively early low temperatures in November and December were probably responsible for the damage, rather than extreme cold, as the overwinter minimum was only -18” C (0° F) (9).

Soils and Topography

European alder grows well on acid soils, and its growth is reduced under the alkaline or near-neutral conditions that are desirable for many other species. During their first growing season in most types of soils alder seedlings form root nodules that are the site of nitrogen fixation. Seedlings already nodulated grow satisfactorily when outplanted on sites with pH as low as 3.3; plants not already nodulated usually die under these very acid conditions *(27,77)*. Nodules develop satisfactorily at pH as low as 4.2 *(8)*, but seedlings were stunted and had poor root systems and chlorotic leaves when grown in clay soil with pH between 8.0 and 8.5 *(63)*. Optimum soil pH for nodulation appears to be between 5.5 and 7.0 (35). Spoil-bank plantations in Ohio and Kentucky verify the minimum pH for satisfactory European alder growth as about 3.4 *(30,55)*. On very acid (pH 2.9) coal spoils in Indiana, alder survival, growth, and root nodule weight were all increased by liming sufficient to raise pH to at least 6.1 (eventually declining to 4.8) ***(41)***. In a greenhouse experiment using acidic Pennsylvania mine spoil, alders did not respond to lime amendments until phosphorus was also added (89).

Both nodulated and nonnodulated alders require molybdenum for nitrogen metabolism (6,421; adequate amounts of Mo are present in most soils, although it may not be available on strongly acid sites. On sites with poor internal drainage, European alder can tolerate iron concentrations normally toxic to many plants (44). On tidal flats adjacent to the English Channel, the chlorine concentration of the soil solution in the root zone of mature alders occasionally rises to 5 percent of that of sea water immediately following equinoctial high tides (78).

European alder is responsive to differences in soil moisture *(5,40)*, and growth often is notably better on lower slopes than on upper slopes. Alder utilizes intermittently moist sites very well (56). It is “a species of stream and lake sides and . . . soils of impeded drainage throughout the British Isles,” although not topographically limited to such sites if rainfall is high *(60)*. Even though alder tolerates heavy soils better than most trees, reduced soil oxygen (especially below 5 percent) inhibits root nodulation and the growth of nodulated plants (57).

In a species with such a broad natural range, altitudinal distribution is bound to be related to latitude. European alder is found at sea level at the northern limits of its range, up to 300 m (985 ft) in Norway, 600 m (1,970 ft) in the Harz Mountains of Saxony, 850 m (2,790 ft) in the Bavarian Mountains, 1300 m (4,270 ft) in the Tyrol and in Greece, and 1800 m (5,900 ft) in the Caucasus (60,881. The most

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common soils on which it grows in North America occur in the orders Histosols, Inceptisols, and Entisols.

Associated Forest Cover

Natural alder communities include ash, birch, willow, and oak, "forming ash-alder wood on low-lying ground of high soil fertility and moisture, alder-willow thickets in areas liable to seasonal flooding, and alder-birch wood on higher lying, less fertile, generally acid soils.... Pure stands are...common, but not as extensive in Britain as, for example, in northwest Germany" *(60)*. European alder and gray willow, *Salix cinerea atrocinerea*, form a tidal woodland near the upper limits of a salt marsh on the Cornish coast. In the absence of disturbance, the alder-willow community succeeds the marsh (78).

Life History

Reproduction and Early Growth

Flowering and Fruiting-European alder is monoecious; flowers of both sexes emerge from buds that begin to develop about 9 to 10 months before pollination. These preformed buds allow an early estimate of the following year's seed crop. Male buds are distinctly longer than female buds-about 1 cm (0.4 in) compared to about 3 mm (0.1 in)—and grow nearer the tips of branchlets. They remain green until December and grow intermittently throughout the winter (74). Female flowers are 1 to 1.5 cm (0.4 to 0.6 in) long when mature; male catkins are from 5 to 13 cm (2 to 5 in) long. They vary in color from tree to tree, over a range from light peach to deep purple. Occasional bisexual catkins are found.

A general calendar of seed formation is as follows *(61,74)*: Styles begin to form in July, year 1; rest period follows from August, year 1 to February, year 2; pollination occurs in February to March, year 2; placenta forms in May, year 2; ovules form in June, year 2; ovary begins to grow from June to July, year 2; embryo sacs are formed in July, year 2; fertilization takes place from late July to early August, year 2; embryo grows throughout August, year 2; embryo ripens throughout September and germination first becomes possible during this month. Seeds are mature when their pericarps turn brown, although the cones remain green until the seeds are released.

As an exception to this calendar, pollination is sometimes delayed until early April in the northeastern United States. The flowering schedule is typically dichogamous.

Most European alder trees are virtually self-sterile *(61)*, but certain selfed trees have produced seed with germination percentages as high as 8 percent *(81)*. Viability of cross-pollinated seed ranged from 8 to 90 percent *(61,81)*. Viability of pollen was greater than 99 percent at the time of collection *(61)* but fell to about 1 percent after 50 days storage (73). Individual trees in Iowa set a good crop of seed every year, but the percentage of filled, viable seed ranged from 0 to 90 percent. Because fertilization occurs in July and August, the developing embryo may be especially vulnerable to heat and moisture stress. Seed with little or no viability was produced in years of severe summer drought (37).

Seed Production and Dissemination-In Europe, alder may not produce a uniform seed crop every year *(61)* but abundant crops are frequent (56). Plantations in the eastern United States seem to bear out both points: seed crops do vary from year to year and they are generally rather heavy. European alder (fig. 1) is precocious; some trees begin to flower at the beginning of their second growing season and by their sixth or seventh year are producing large

Figure *l-Collecting seeds from a European alder tree in southern Illinois. At age 14 this tree was 16 m (51 ft) tall and 24 cm (9.3 in) in d.b.h.*

quantities of seeds. Several hundred strobiles may develop on a 6- to 9-m (20- to 30-ft) tree, and in summer and early autumn the mass of maturing fruit approximates the mass of foliage (74). Seeds average 60 per catkin *(60)*. The seeds are very small brown nuts, ranging from about 240,000/kg (110,000/lb) (56) to as many as 1,400,000/kg (639,000/lb) (87).

Seeds begin to fall in late September or early October and the best seeds usually fall first *(11,92)*. Seed dispersal continues throughout the winter. Very few alder seeds remain viable beyond the first germination season (62). Seed production as high as 18 kg/ha (16 lb/acre) has been achieved in a 14-year-old grafted orchard in southwestern Germany; yields of 5 to 13 kg/ha (4.5 to 12 lb/acre) were more typical *(54)*.

Although European alder seeds can germinate immediately after they are shed, stratification and cold treatment enhance their germination capacity (85). Seeds collected before strobiles turn brown require several months of afterripening to germinate *(60)*. Epigeal germination in the nursery is prompt; it begins 10 to 20 days after spring sowing and is essentially complete within 2 weeks. Germination is notably better at pH 4 than at higher or lower pH *(85)*.

Production of containerized alder seedlings allows them to be inoculated with *Frankia* and assures their nodulation prior to planting. A 1 to 1 ratio of peat and vermiculite in the potting mix is recommended *(7)*.

European alder seeds have no wings; therefore, despite their small size they are usually not spread more than 30 to 60 m (100 to 200 ft) by the wind, although they may occasionally be blown much farther over the top of crusted snow. Where wind is the only likely means of dissemination, alder saplings are rarely found more than 20 to 30 m (65 to 100 ft) from the parent tree. The seeds contain an air bladder and float in water, and McVean holds that rather than wind, running water and wind drift over standing water are the principal agents of dispersal (62). Naturalized European alder stands in the United States are most commonly found adjacent to streams.

Seedling Development-Seeds buried more than 0.5 cm (0.2 in) deep germinate satisfactorily but many of the new seedlings fail to emerge (62). The soil need not be saturated to gain good seed germination, but high air humidity is essential. In regions with only 50 to 65 cm (20 to 25 in) of annual rainfall, "alder seedlings will only establish where the surface soil falls within the capillary fringe of the water table so that it remains constantly moist for 20 to 30 days in the spring (March to May)" *(63)*.

Alder seedlings can survive, although not thrive, under conditions of flooding that would kill off the seedlings of most other forest trees. In a British experiment, seedlings did not live indefinitely with their entire root systems completely submerged and were quickly killed by such treatment during the growing season. Nevertheless, when the water level was maintained flush with the top of the soil, the more robust seedlings were able to produce adventitious roots at the soil surface and their growth was hindered very little (63). The original roots of European alder can grow actively during periods of flooding lasting for as long as 1 week and resume growth after longer periods of flooding *(31)*. In another greenhouse study, alder seedlings were successfully grown in oxygen-free soil, outperforming white willow *(Salix alba)* under such conditions *(10)*.

Growth of young potted European alder seedlings was not inhibited by addition of foliage litter of six herbaceous species that did inhibit growth of black locust *(Robinia pseudoacacia)*. Alder seedling growth and root nodulation were more than doubled by addition of crownvetch *(Coronilla varia)* litter (49).

A light intensity equivalent to about 5 percent of full daylight is essential for first-year alder establishment; for survival in subsequent years about 20 percent of full daylight is required (63). "First-year seedlings and 2- to 3-year-old plants up to 5 cm (2 in) in height are frequent in some woods, but complete internal regeneration is seldom seen. Regeneration tends to be peripheral, or to occur with the formation of an even-aged stand" *(60)*.

Natural alder seedlings in Croatia grow to be about 0.5 m (1.7 ft) tall in their first year *(32)*, but seedlings in American nurseries are not always as large.

Alder seedlings are associated with actinomycetes and mycorrhizae. Development of nitrogen-fixing root nodules in European alder is induced through root-hair infection by actinomycetes of the genus *Frankia*. Actinomycetous endophytes isolated from European alder are cross-infective with other *Alnus* species and even other genera such as sweetfern *(Comptonia)* and bayberry *(Myrica)* (38). Thus, even though European alder is not native to the United States, suitably infective actinomycetes may be available wherever it is planted *(20)*. On the other hand, in a greenhouse study, European alders inoculated with native European endophytes grew six times faster than those inoculated with a *Comptonia* isolate *(59)*. Strongly infective *Frunkia* strains are not necessarily effective in stimulating rapid alder growth, and those that produce spores may be weakly parasitic, rather than symbiotic (58).

European alder has been found associated with at least six mycorrhizal fungi. Suitable symbionts appear to be widely available, as both ectomycorrhizae and endomycorrhizae were found on root samples taken from European alder plantations in Iowa, on coal strip mines in Ohio, and on kaolin spoils in Georgia (38). Ecto-, endo- and ectendomycorrhizae were described as associated with European alder on Bohemian lignite spoil banks. The endomycorrhizae were found only below 10 cm (4 in) depth (66).

Vegetative Reproduction-European alder commonly sprouts from the stump after cutting, and live branches can be layered successfully. Root suckers are rare *(60).* In coastal southern Sweden, alders live to maximum age of 100 years but frequently produce basal sprouts and form multi-stemmed stumps following death of the original stem (18).

Air-layering of alder shoots has been 89 to 100 percent successful (84). The rooting ability of greenwood cuttings of European alder seedlings less than 4 years old was found to be generally high; over an 18- to 20-month period, 100 to 200 cuttings were successfully rooted from each ortet (25).

Alnus glutinosa can be readily propagated by *in vitro* tissue culture. Plantlets of several clones were rooted within 3 weeks, subsequently transferred to soil mix, and maintained in good physiological state for as long as 4 years (90).

Sapling and Pole Stages to Maturity

Growth and Yield-Height growth begins in mid-April and continues through July or August. Saplings may continue growing into September or October (59,101). In the mountains of Czechoslovakia, 90 percent of diameter growth takes place between mid-May and mid-August, a growing season almost identical to that of European beech *(Fagus sylvatica) (12).* In Switzerland, alder root growth commenced about 4 days after the beginning of vegetative bud swelling and about 5 weeks before the beginning of branch extension growth *(51).* Root growth resumes in October and continues throughout the winter except when the ground is frozen (79).

Height growth of alder seedlings planted on rather acid (pH 4.3 to 4.5) strip-mined land in Ohio falls between normal yield values (table 1) for site classes I and II at age 16 (29). On a moderately permeable bottom-land site in southern Illinois, g-year-old European alder outgrew predicted height values and averaged 11.2 m (36.8 ft) tall, and 13.7 cm (5.4 in) in d.b.h. (72). Height growth slowed markedly (80) over

Table l-Height and basal area growth of European alder in Germany (88)

	Site class					
	I		II		III	
Age	**Height**	**Basal area**	**Height**	**Basal area**	**Height**	**Basal area**
yr	*m*	*m²/ha*	*m*	*m²/ha*	*m*	*m²/ha*
20	15	17	11	14	9	11
30	18	22	15	18	12	14
40	21	25	17	20	14	16
50	23	27	19	22	15	17
60	24	28	20	23	16	18
70	25	29	21	24	17	18
80	26	30	21	24		
yr	*ft*	*ft²/acre*	*ft*	*ft²/acre*	*ft*	*ft²/acre*
20	49	74	36	61	29	48
30	59	96	49	78	39	61
40	69	109	56	87	46	70
50	75	118	62	96	49	74
60	79	122	66	100	53	78
70	82	126	69	105	56	78
80	85	131	69	105	—	—

Table 2—Height growth of European alder in Croatia (32)

	Seedlings			Sprouts		
Age	**Annual growth**	**Total height**	**Mean annual growth**	**Annual growth**	**Total height**	**Mean annual growth**
yr			*m*			
2	0.6	1.1	0.5	1.1	2.0	1.0
4	0.8	2.6	0.6	1.5	4.8	1.2
6	1.1	4.7	0.8	1.1	7.1	1.2
8	1.3	7.3	0.9	1.0	9.1	1.1
10	1.4	10.1	1.0	0.9	11.0	1.1
12	1.3	12.7	1.1	0.9	12.7	1.1
14	1.0	14.8	1.1	0.8	14.3	1.0
16	0.8	16.5	1.0	0.7	15.8	1.0
18	0.5	17.6	1.0	0.7	17.2	0.9
20	0.4	18.5	0.9	0.6	18.4	0.9
yr			*ft*			
2	1.9	3.6	1.8	3.5	6.6	3.3
4	2.7	8.5	2.1	4.9	15.8	3.9
6	3.6	15.3	2.5	3.5	23.4	3.9
8	4.4	23.8	3.0	3.2	29.9	3.7
10	4.6	33.0	3.3	3.0	36.0	3.6
12	4.2	41.6	3.5	2.8	41.7	3.5
14	3.3	48.6	3.5	2.6	47.0	3.4
16	2.5	54.0	3.4	2.4	51.9	3.3
18	1.8	57.9	3.2	2.2	56.3	3.1
20	1.3	60.7	3.0	1.9	60.3	3.0

the next 5 years in this widely spaced plantation, and at age 14 the trees averaged 12.3 m (40.4 ft) tall and 20.1 cm (7.9 in) in d.b.h. (table 2). European alder usually reaches two-thirds of its maximum height by age 25 (33) but may survive for 120 years on the best sites, growing to be at least 1 m (3 ft) in diameter *(60)*. The root wood of European alder has lower specific gravity than the stem wood but longer fibers with thinner walls *(100)*. In an Ohio stripmine plantation, stem wood specific gravity averaged 0.39 and did not vary with age or geographic origin of the trees. Fiber length increased from 0.71 mm (0.28 in) at age 5 to 0.93 mm (0.36 in) at age 17 (83).

Representative percent chemical composition of European alder from two points of view has been reported. The first was based on total aboveground biomass, 4-year-old trees *(104);* the second was based on leaf litter from four stands (69):

	N	P	K	Ca	Mg	Mn
Biomass	0.80	0.60	0.30	0.63	0.07	0.02
Litter	2.68	0.05	0.15	0.20	0.23	

Rooting Habit-Alder has been characterized as possessing an extensive root system of both surface and deep branches, which enables it to survive on either waterlogged soils or those with a deep water table *(60)*. In Germany, European alder is considered to be the deepest rooting indigenous tree species (86). Alder's deeply penetrating taproots often extend well below normal water table; if the water level falls, these roots are well situated to use deep-lying soil moisture not available to the upper portion of the root system. This may explain alder's outstanding success on spoil banks *(37,64)*.

Generally, there are two kinds of alder root nodules. One is a large, perennial, usually single nodule sometimes 5 cm (2 in) or more in diameter *(21)* and most often situated near the root crown. These nodules may persist as long as 10 years, with those in the 4- to 5-year age class making up the greatest proportion of the weight of nodules per tree *(1)*. The other type is ephemeral, much smaller—typically 1.5 to 3 mm (0.06 to 0.12 in) in diameter—and generally distributed throughout the surface root system. Becking found that molybdenum-deficient alder plants formed many small nodules of much reduced total dry weight and exhibited associated nitrogen deficiency. Plants with an adequate molybdenum supply had mainly single large nodules (6).

The most striking effect of alders on soil is nitrogen enrichment. Not only is alder leaf litter rich in nitrogen *(68)*, but many nitrogenous compounds are heavily concentrated in alder roots and root nodules (99). In European alder seedlings, rate of nitrogen fixation is closely related to nodule fresh weight and total plant dry weight, suggesting that selection for growth should also achieve gains in nitrogen fixation (4). In Quebec, 3- and 4-year-old alders planted at 33 cm by 33 cm (13 in by 13 in) spacing fixed nitrogen at an annual rate of 53 kg/ha (47 lb/acre) *(15)*.

Fixation of atmospheric nitrogen by alders takes place in root vesicles (67) and nodules *(8)*. In a greenhouse experiment, maximum nitrogen fixation in young European alder plants occurred in late August; throughout the growing season about 90 percent of the nitrogen fixed was steadily transferred from the nodules to the rest of the plant *(91)*. In an alder grove growing on peat in the Netherlands, nitrogen fixation was also found to peak in August *(1)*.

European alder (as well as other *Alnus* species) differs from most deciduous tree species in retaining much foliar nitrogen in the leaves until they fall *(17)*. In a southern Illinois plantation, nitrogen content of leaves decreased by only one-sixth from midsummer until leaf fall. At the time of the last collection, in mid-November, leaf nitrogen content was about 2.6 percent; thus there was a substantial quantity of nitrogen to be dropped in the leaf litter *(21)*.

In Finland, a 13-year-old European alder plantation and a 55-year-old natural stand were sampled for 4 years. Alder litter averaged 2690 and 3705 kg/ha (2,400 and 3,305 lb/acre) per year (ovendried), respectively, and contributed about 82 percent of the total annual litter production, Total nitrogen content of the leaf litter averaged 77 kg/ha (69 lb/acre) per year, reaching a high of 101 kg/ha (90 lb/acre) in 1 year in the plantation. NH_4-nitrogen in the upper 3-cm layer of soil rose from 180 mg/kg (180 p/m) before leaf fall to 270 mg/kg (270 p/m) after leaf fall, indicating that at least part of the nitrogen of alder leaf litter was rapidly mineralized (69).

Prodigious amounts of litter can accumulate under alder stands. For instance, 10 species of pines and deciduous trees were planted on a Kentucky strip mine with and without alternate rows of European alder. After 10 years, 28.7 t/ha (12.8 tons/acre) of litter accumulated in the plantings without alder, while 61.7 t/ha (27.5 tons/acre) built up under the stands with a 50 percent alder component. The relative contribution of alder leaf fall and increased litter production of the other species, stimulated by the alder, could not be determined. In the spring of the 10th growing season, the pH of the spoil beneath the stand containing alder was significantly lower than the plantings without alder. Similarly, the concentration of total soluble salts was consistently higher, both spring and fall, in the stands with alder than in those without (75).

European alder leaf litter readily gives up water-soluble organic substances, losing 12 percent of its dry weight after only 1 day's leaching in cold water. Alder litter was also found to decompose faster than that of beech or oak *(70)*. The C:N ratio of alder foliage suspended in a stream declined rapidly from 19 to about 13 within a month after leaf fall, then more slowly to 11 (near the effective mineralization optimum) after 6 months *(13)*.

Other components of alders also accumulate considerable nitrogen. In a plantation on a good alluvial site in western Kentucky the following nitrogen contents (percent dry weight) were measured at the end of the fourth growing season (adapted from 104):

Foliage	3.15
Branches	1.02
Bolebark	1.10
Bolewood	0.26
Total tree (aboveground)	0.79

Even young alders can fix and add significant amounts of nitrogen to soil. A Padus silt loam in Wisconsin averaged 966 mg/kg (966 p/m) of nitrogen in the upper 4 cm (1.5 in) of dry soil before l-year-old European alder seedlings were planted. After two growing seasons, soil nitrogen (at the same depth) had increased 222 mg/kg (222 p/m) in soil immediately adjacent to the alders and by 158 mg/kg (158 p/m) at a distance of 15 cm (6 in) (39).

Reaction to Competition-"The alder is primarily a pioneer and opportunist species, and is capable of direct colonization of even the rawest of soil material.... The species acts as a pioneer on hydroseres, being capable of colonizing at very early stages in the primary succession if good seed is available. Alder carr (deciduous woodland or scrub on a permanently wet, organic soil) does not succeed an earlier *Salix* and *Rhamnus* carr, though these species may colonize simultaneously, and pure alder carr eventually results from the greater vigour and longevity of the alders" (65).

In central Switzerland, alder is considered to be more shade tolerant than willow *(Salix* spp.), larch *(Larix* spp.), poplar *(Populus* spp.), birch *(Betula* spp.), or Scotch pine *(Pinus sylvestris)*; equal in tolerance to ash *(Fraxinus* spp.); and less tolerant than eastern white pine *(Pinus strobus)* or Douglas-fir *(Pseudotsuga menziesii) (50)*. Overall, it is classed as intolerant of shade (18).

In Yugoslavia and Germany, European alder is grown on 40- to 80-year rotations, depending on intensity of thinning and products desired. The stand is clearcut at the end of the rotation and replanted with l-year seedlings or l-l transplants.

Nursery practice for European alder is fairly routine, and l-year seedlings are usually large enough for outplanting. Liberal irrigation following sowing is essential for good seed germination.

Alder has generally beneficial effects on associated plants. Part of the nitrogen fixed by alders soon becomes available to other species in mixed stands, especially through mineralization of nitrogen leached from litter. Norway spruce *(Picea abies)* grown in pots with European alder "obtained nitrogen fixed in the root nodules of alder although leaves falling in autumn were always carefully removed" *(98)*.

In a 3-year-old Wisconsin plantation, hybrid poplars in a plantation spaced at 1.2 by 1.2 m (3.9 by 3.9 ft) grew 21 percent taller in a 1:2 mixture with European alder than when grown without alder (4.9 m versus 4.0 m; 16.0 ft versus 13.1 ft). This growth increase corresponded closely with that achieved through optimal ammonium nitrate fertilizer treatment, which stimulated a 24 percent increase (39). Similar results were obtained in Quebec where mixed plantings of two alders per poplar yielded slightly more total biomass at age 3 than pure alder plantings and 50 percent more than pure hybrid poplar *(16)*.

European alder often is recommended for use in mixed plantings with other species on nitrogen-poor sites. On strip-mined sites in eastern Kentucky, 10 coniferous and broadleaved species were grown in alternate rows with European alder at 2.1 by 2.1 m (6.9 by 6.9 ft) spacing; after 10 years, trees grown in mixture with alder were 11 to 84 percent taller and 20 to 200 percent larger in diameter than the same species grown without alder (75).

In northern Bohemia, *Populus x berolinensis* used for strip-mine reclamation averaged 12.5 m (41 ft) tall at age 14 in pure plantings but grew to 14 m (46 ft) in mixture with *Alnus glutinosa*; poplars in the mixed planting were also much straighter (24).

In southern Indiana, European alder seedlings were interplanted into a 2-year-old plantation of black walnut *(Juglans nigra)* on well-drained silt loam soil. Ten years after interplanting, walnuts grown in mixture with alder averaged 5.3 m (17.5 ft) tall against 4.2 m (13.8 ft) in pure stands; alder stimulated an increase in walnut diameter from 5.6 cm (2.2 in) to 6.9 cm (2.7 in) *(14)*. In contrast, at four locations in Illinois and Missouri, alder interplanted with walnut suddenly declined and died after 8-13 years. Allelopathy caused by juglone was the only cause of death that could be substantiated *(80)*.

Damaging Agents-In a Scottish plantation survey, European alder suffered less damage by deer browsing and rubbing than did birch, willow, or other hardwood species (2). In contrast, deer browsed more than half the European alder seedlings in a 2-year-old plantation in Pennsylvania; damage was much less on Japanese larch *(Larix leptolepis),* white spruce *(Picea glauca),* eastern white pine, and red pine *(Pinus resinosa) (26).*

Dozens of insects and diseases have been observed on European alder but few cause serious damage. Among pests recognized as potentially troublesome is the striped alder sawfly, *Hemichroa crocea,* a native of Europe that is now found across northern United States and Canada. It produces two generations per year. From July through September larvae occasionally eat all of the alder leaves except the midrib and larger veins (93).

The European alder leafminer, *Fenusa dohrnii,* is another introduced species. It makes blotch mines on alder leaves in the northern United States and southeastern Canada (5). The alder flea beetle, *Altica ambiens alni,* feeds on both surfaces of alder leaves from Maine to New Mexico. It is sometimes a pest of alders in recreational areas and along roadsides (93). The woolly alder aphid, *Prociphilus tesselatus,* is distributed throughout the eastern United States and is often abundant on alder. Although it causes little direct damage, it is suspected of weakening the trees and providing infection courts for subsequent fungal attack.

Several fungus species have been isolated from *Alnus glutinosa* trees that died back following woolly aphid infestations. They include *Botryodiplodia theobromae* (76) which has not been confirmed as pathogenic. In an *A. glutinosa* seed production plantation in Kentucky, *Phomopsis alnea* caused basal stem cankers and eventual mortality as great as 17 percent (71). In northern Mississippi, occasional alder trees infested with woolly aphids are heavily damaged by sapsuckers *(103).* Alder seems to be very resistant to chronic ozone fumigation (45); in contrast, it is more susceptible to SO_2 damage than most species (94).

Special Uses

European alder is valuable for wildlife. Because the cones open gradually and release seed throughout the winter, they are a dependable source of food for seed-eating birds such as pine siskins and goldfinches. European alder is recommended for use in shelterbelts to provide cover for pheasants. When combined with *Prunus laurocerasus* and *Sorbus aria,* it makes a compact planting suitable for establishment adjacent to cropland (34).

Alders have been recommended for afforestation of disturbed areas throughout much of the temperate world *(46,52).* Their tolerance of low pH and their rapid growth, abundant leaf litter production, and ability to fix atmospheric nitrogen combine to make European alder especially desirable for planting on spoil banks, which typically contain little organic matter and available nitrogen.

Establishing European alder on mined sites apparently improves their suitability for earthworm habitat. Ten adult *Lumbricus terrestris* worms were released in a 4-year-old *A. glutinosa* plantation growing on calcareous coal spoil in southern Ohio. After 5 years the population had increased to $60/m^2$ ($6/ft^2$) as far as 15 m (50 ft) from the point of introduction and was apparently still increasing, with obvious desirable implications for hastening soil development *(97).*

Alder is useful in urban forestry. A system for producing containerized alder seedlings suitable for park and roadside planting has been described. Trees grown in Iowa according to these methods averaged 94 cm (37 in) tall after only 8 months (19).

Biomass use of European alder has potential. On a river terrace site in northern Alabama, 6-year-old European alder produced more than six times as much volume per tree as sycamore *(Platanus occidentalis)* of the same age (22). Alders in southern Illinois, planted at only 998 trees per hectare (404/acre) on a bottom-land site, produced 54.7 t/ha (24.4 ton/acre) at age 9 (dry weight of entire tree, above ground) (72). Alder may be a more promising species to grow in short-rotation, intensive-culture plantations for cattle feed. Protein yield was nearly that of alfalfa (3).

Aboveground parts of European alder have energy values of about 5 Kcal/g (9,000 Btu/lb) dry weight. Calorific value of branchwood is 10 percent greater than that of bolewood (43).

Genetics

Population Differences

In an extensive progeny test of select European alder parent trees, heritability of height growth was good at age 7. Most good clones performed consistently when used as either male or female parents. The general superiority of alders from the moraine region of upper Bavaria was confirmed *(102).*

Races and Hybrids

Over the broad range of European alder, racial development is to be expected, but within regions, variation is sometimes slight. Fifteen European alder provenance collections, grown on calcareous spoil banks in southern Ohio for 16 years, differed sharply in both growth and survival. Most of the trees originated in central and north-central Europe; survival was best for three seedlots of central German provenance. Trees from Diessen, Bavaria, grew to be 21 percent taller and 20 percent larger in diameter than the plantation mean and averaged 0.57 m (1.87 ft) per year in height growth over the past 10 years. Alders of Uppland, Sweden, provenance were almost complete failures, being only 3.5 m (11.5 ft) tall with 11 percent survival after 16 years (29).

The 16-year results reported above are reasonably consistent with those at age 6, with one striking exception. Trees from Peiting, Bavaria, formerly second tallest in the plantation *(28)*, have virtually collapsed, with survival declining to 37 percent, and height growth over the past 10 years least of all except for the trees from Uppland, Sweden (29). Similar results are reported from European alder trials in the Netherlands, where trees from three German seed sources grew rapidly for 7 years and then slowly for the following 3 years (96). The need for caution in making early selections is obvious.

In a larger but younger provenance trial in Pennsylvania, most trees burst buds with a 4-day period well before the beginning of the frost-free season. Most of the fastest growing trees originated from the central part of the species' natural distribution. About half the variation in total height was due to rate of growth; the other half was due to length of the growing season (23).

European alders that grow fastest are more likely to be single-stemmed. At age 6 in the Ohio test, the correlation between height and number of stems per tree was -0.31 (28).

European alder hybridizes readily with many other alders. Particularly vigorous hybrids have been reported for *A. cordata x A. glutinosa (48), A. glutinosa x A. incana (47), A. glutinosa x A. rubra (53),* and *A. glutinosa x A. orientalis (95).*

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