GENETIC AND SILVICULTURAL RESEARCH PROMOTING COMMON WALNUT (*JUGLANS REGIA*) FOR TIMBER PRODUCTION IN THE UNITED KINGDOM

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ABSTRACT—A combination of genetic and silvicultural research is required to improve the viability of common walnut for timber production in the UK. A summary of a research programme, initiated in 1996, is provided. Establishment of walnut plantations using tree shelters indicated positive benefits using 0.75 m shelters but larger shelters (1.20 m) caused early flushing and increased dieback. Direct seeding trials indicated that pre-treatment of seed with gibberellins was highly effective in reducing the need for lengthy pre-treatments and promoted 87% germination. Artificial application of nitrogen fertiliser on newly established walnut trees indicated that applications up to 500 kg ha^{-1} had no effect on survival or early growth. Assessments of a range-wide collection of walnut, including provenances from Kyrgyzstan, point to high variability in flushing and growth between provenances and progenies 4 years after establishment. Genotype by site interaction within the three provenance trials is evident. Adoption of new, to the UK, silvicultural systems incorporating tree and shrub nurses indicated promising benefits from using the nitrogen-fixing nurse species autumn olive and Italian alder.

Common walnut (*Juglans regia* L.) is an ancient introduced species to the United Kingdom but today there are probably fewer trees than at any time since the late sixteenth or early seventeenth centuries. Interest in walnut as a timber waned with the increasing availability of tropical hardwoods from the early nineteenth century onwards and it has been infrequently planted in the UK since that time, particularly as a forest tree. Supplies of hardwoods such as mahogany are now, nearly 200 years later, becoming scarce. There is also an increasing awareness by European consumers that the use of tropical timbers may contribute to deforestation, resulting in a reluctance to buy them. There are therefore good reasons to believe that valuable, decorative, temperate hardwoods are likely to be in much greater demand as tropical supplies decline.

Common walnut is perhaps the finest of these valuable species, and is seen as a tree that could regain the place it had centuries ago, as the provider of high quality timber on relatively short rotations. The wood is used for making quality furniture and producing highly figured veneers, usually from burrs, which are used for cabinet-making and decorative panels. At present however, common walnut is often overlooked by foresters due to its reputation as being a species which is site demanding, usually of poor form and which suffers badly from the effects of frost.

The tree phenotypes seen in the UK today are often of poor form for timber production because their likely origin is from European trees originally selected for nut production. Phenotypes for timber or nut production are generally viewed as incompatible because good phenotypes for timber (e.g., long and straight stemmed, finely branched) have deliberately been selected against. Short-boled, spreading and branched trees were sought for high nut productivity and ease of harvesting. Additionally, some phenotypes in Britain may originate from ancient introductions, taken from environments unsuitable for widespread introduction to the British climate.

To encourage a revival of interest in walnut in the UK and to promote best practise, a number of activities were necessary:

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Citation for proceedings: Michler, C.H.; Pijut, P.M.; Van Sambeek, J.; Coggeshall, M.; Seifert, J.; Woeste, K.; Overton, R.; Ponder, F., Jr., eds. 2004. Black walnut in a new century, proceedings of the 6th Walnut Council research symposium; 2004 July 25-28; Lafayette, IN. Gen. Tech. Rep. NC-243. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station. 188 p.

1. research directed towards improving initial establishment;

2. desirable, straight stemmed and finely branched trees needed to be selected to suit the climatic conditions of the UK;

3. the collected genotypes needed to be tested in a range of conditions in the UK;

4. novel plantation designs needed to be tested to improve silvicultural conditions;

5. research programmes and promotion of walnut growing needed to be coordinated.

PLANTATION ESTABLISHMENT

Tree Shelters

Background and Method

Tree shelters are widely used in the UK as a means to protect establishing trees from pests and additionally to provide protection from herbicides in combination with micro-climatic benefits. Costs for both shelter and supporting stake vary according to size but for an average 0.75 m shelter/stake costs approximately $1.6 at current prices, and are often more cost effective than fences when the trees are spaced widely. An experiment was established in 1996 testing the effects of two common sizes of shelter (0.75 and 1.2 m) and a control (no shelter) on the establishment and early growth of common walnut, planted as bare-rooted transplants (Hemery and Savill 2001). Observations were made on height and stem diameter growth, flushing (leaf burst) and dieback over a 4-year period.

Results and Discussion

Treeshelters were beneficial for both tree height increment and stem diameter growth however, the 1.2 m tall shelters promoted earlier flushing than the other shelter treatments, resulting in a risk of increased frost damage (Hemery and Savill 2001). Additionally, a substantial degree of stem dieback occurred during one dormant season in the 1.2 m shelters when 46% of tree height was lost, whereas there were no significant differences for dieback between those trees without shelters and those in 0.75 m shelters (20% and 15%, respectively). Hemery and Savill (2001) therefore recommended medium sized (0.60 or 0.75 m) shelters where possible for the successful establishment of walnut. Medium-sized tree shelters were therefore adopted for most of the experiments described here and are widely adopted by landowners planting walnut in the UK.

Direct Seeding

Background and Method

Walnut plantations can be costly to establish both in terms of plant cost (typically equivalent to $1.6 or more per 60 – 90 cm transplant in the UK) and labour due to the large taproot. Walnut also has a reputation as being sensitive to transplant shock and intolerant of damage to the taproot (Popov 1981). Direct seeding was proposed as an alternative method to establish a walnut plantation although methods of ensuring adequate germination and growth needed to be determined.

The effectiveness of four different seed preparation techniques in relation to walnut establishment by direct seeding was tested in a trial sown in spring 2001. The trial was a randomized complete block design with five nine-tree replicates per treatment. In addition to a control (no pre-treatment), seeds were stratified according to recommended practise (Dirr and Heuser 1987) where seeds were placed in damp peat (sedge peat -neutral pH) and stored between 0 and 4° C for 4 - 6 weeks. Another treatment included water-soaked seeds where these were partially opened at the basal joint with a blunt knife and soaked for 48 hours in water, immediately preceding sowing. The final treatment was GA3 soaked seeds, where seeds were partially opened at the basal joint with a blunt knife but soaked for 48 hours in a solution of gibberellic acid (GA_3 – Sigma 7645) at 48 ppm[2], immediately preceding sowing. Gibberellins were successfully used by Hemery (2000) in nursery trials of walnut seed germination.

The seeds were sown by placing them at twice their width below ground and then covered by sedge peat. A tree shelter was placed over each sown seed. Germination and tree height growth data were assessed and analyzed using Genstat (Lawes Agricultural Trust, Rothampstead Experimental Station, UK).

Results and Discussion

There were no significant differences for germination between different pre-treatments. The lowest mean germination rate was for control treatments at 76% and highest for GA3-soaked seed at 87%. Overall 80% of seeds germinated. In the first year following germination, trees that had grown from stratified and GA3-soaked seeds grew more ($p < 0.05$) than those water-soaked and control treated. By year 2 and onwards however,

[2]Example calculations: 45 seeds of mean volume 14.5 cm^3 each = 652 cm^3 total volume whilst approximate bucket volume = 2356 cm^3. Remaining bucket volume (2356-652) = 1704 cm^3 (1.7 litres). GA_3 required at 100 ppm = 0.1g l-1 = 0.17g for 1.7 litres of water.

there were no differences for height between the treatments.

The high germination rates achieved by the use of gibberellins indicate a highly practicable way of pre-treating seeds for direct sowing but further research is needed to study methods that may improve germination in comparison to traditional methods. This research does indicate the efficiency of establishing walnut by direct seeding, particularly in terms of the cost of a seed, which is typically only 2% the cost of a transplant. Although not tested in an experimental framework, it is interesting to note that the 3-year-old seedlings in the trial averaged 98 cm tall compared to 'control' common walnut trees in a neighboring trial (described below) whose mean height was 166 cm after the same three growing seasons, being planted at 46 cm tall.

Nitrogen Fertiliser

Background and Method

Visual observation of many young walnut plantations on ex-farmland in the UK, where leaves often turned yellow and growth slowed 5 to 8 years after establishment, indicated nitrogen (N) deficiencies. Foliar analysis subsequently confirmed critical levels of N in these cases 2.0% - 2.5% element N in dry weight (Bonneau 1995).

A trial neighboring the direct seeding experiment was established in 2001 to test the effects of applying artificial nitrogen on the establishment and early growth of walnut transplants, both common and black (*Juglans nigra*). The trial was planted in ground that had been fallow for 7 years preceding establishment of the trial. It was laid out as a full factorial incorporating the two walnut species and six nitrogen treatments in a randomized complete block experiment with two replicates. In addition to a control (no N applied) there were five N application treatments covering the range of recommended rates of N in addition to low and high extremes (100, 200, 300, 400 and 500 kg N ha^{-1}). Savill and others (1997) stated that the normal range would be 150-250 kg of element N ha^{-1}. The two walnut selections were common walnut (provenance RA464) and black walnut, both sourced from France. The N was applied once at planting, in the form of ammonium nitrate (NH_4NO_3) in which N was present at 34.5%, and again at the start of the third growing year. Survival and tree height data were assessed and analyzed using Genstat.

Results and Discussion

After both growing seasons following application of nitrogen (years 1 and 3) there were no significant differences for height growth between the different nitrogen treatments. Over the three growing seasons the common walnut grew more in height ($p > 0.05$) than black walnut but was this was not attributable to the nitrogen treatments, the interaction being non-significant. Trees subjected to the highest dose of nitrogen (500 kg N ha^{-1}) grew less (80 cm) than all other treatments (range 96 – 106 cm) but these differences were non-significant. Extreme high doses of nitrogen would be expected to have a negative effect on growth but the results of this experiment indicate than nitrogen can be applied at nearly double the recommended rate without adversely effecting growth. More importantly it indicates that applying nitrogen may be a costly exercise, both in terms of unnecessary monetary expense and environmental pollution, and therefore not recommended.

SELECTION OF GENOTYPES

Natural Range of Common Walnut

The natural range of common walnut is confined to the Asian continent extending across 21 modern political boundaries: from Turkey, Azerbaijan, Armenia, Russia, Georgia, and Iraq (Kurdistan) in the west, across the northern lands of Iran and Afghanistan and the heart of central Asia in the independent states of Kazakhstan, Turkmenistan, Uzbekistan, Kyrgyzstan, Tajikistan and their giant neighbor China in the Xinjiang Autonomous Region, formerly 'Chinese Turkestan', extending further south in a narrowing range nestling in the mountains of Pakistan, northern India and Nepal, and finally reaching its eastern extent in Bangladesh, Myanmar (Burma), Bhutan and southern China (Nekrassowa 1927, Schmucker 1942, Berg 1950, Browicz 1976, Davis 1982, Puri and others 1983, Komarov 1985). Jalas and Suominen (1976), and Tutin and others (1993), reported that common walnut might be native to Greece and elsewhere in the Balkan Peninsula.

Seed Collections

In provenance selection, the movement of seed from a source of origin that is very different to the introduced location can be problematic if high altitude or high latitude sources are moved to low altitudes or low latitudes, or indeed the reverse (Zobel and Talbert 1984). However, high altitude sources from low latitudes can often be introduced successfully to low altitude locations at high latitudes (Zobel and Talbert 1984). The prime area for concentrating sampling was Kyrgyzstan which, although situated 10° south of the UK, it is situated at the northern limit of the natural range of the species (Schmucker 1942, McGranahan and Leslie 1991). Therefore the seed sources from this mountainous country, where the average elevation of collections made were 1,460 m above sea level (a.s.l.), provided a possible source for successful introduction due to the altitude difference between the two locations (UK trial sites ranged from 15 to 245 m a.s.l.).

The genetic resources of forest trees are usually located in primeval or ancient forests (Frankel and others 1995). Kyrgyzstan, containing 25,600 ha of natural walnut forest (Musuraliev 1998), was therefore the main focus for seed collecting with the dual purposes of sampling genetic variation (Hemery and Popov 1998) and identifying superior genotypes for timber production.

Eleven provenance collections, incorporating 253 half-sib progenies, were sampled from Kyrgyzstan in September 1997 during a 3-week expedition (Hemery 1998). On average, 23 trees were sampled from each provenance location, each containing a wide variety of tree phenotypes, ranging in height from 7 to 34 m and in DBH from 13 to 128 cm (Hemery 2000). A wide array of tree characteristics were assessed including height to first branch, branch angle, crown diameter, stem straightness, presence/absence of burrs and many seed parameters. Provenance sites were surveyed for accurate location, altitude, aspect, slope, soil type, forest species diversity and basal area.

A further 13 provenance collections (and 122 progenies) were amassed through collaboration with research institutes and individuals across the natural and introduced ranges of the species covering 12 countries. Overall 18 provenances contained progeny-level data.

PROVENANCE AND PROGENY PERFORMANCE

Method

The 375 common walnut genotypes were established across three provenance/progeny trials in southern England during winter 1998. The three provenance trials are arranged as randomized complete block designs with unbalanced multiple-tree plots. The largest of these (Oxfordshire) was a combined provenance and progeny trial containing 18 provenances and 199 half-sib progenies. The progeny trial in a randomized incomplete block design with single-tree plots. Tree heights and stem diameters were measured annually and flushing (leaf-burst) assessed using a scoring system developed for this research, on two days in spring 1999, and analyzed using the Kruskal-Wallis non-parametric test. Survival percentages were arcsin transformed for analyses. All statistical analyses were conducted on plot means using Genstat.

Results and Discussion

Across all three field trial sites survival has been impressive at 98.4% after four growing seasons. Within the 18 provenances with progeny-level data, mortality was only observed within the Kyrgyz provenances (mean 97.4% survival).

At the end of the fourth growing season (2002) mean tree height was 122 cm but variable between sites ($p < 0.001$) and provenances ($p < 0.001$). Provenance x site interaction was also present ($p < 0.001$) with all main 18 provenances being tallest at the Somerset site and shortest at the Gloucestershire site (Fig. 1). Notably, provenance T1 (Trabzon region, Turkey) was twice the height ($p < 0.001$) at Somerset than at Gloucestershire.

Flushing was highly variable for provenances ($p < 0.001$) on Julian day 85 (March 26th 1999), between the earliest flushing provenances E1 (Spain), T1 and T2 (both Turkey) and the latest flushing provenance J1 (Tajikistan). Within the Kyrgyz provenances (K1-11) there was no significant variation for flushing at day 85. On day 97 (April 7th 1999) provenances K1 and J1 were the only provenances ($p < 0.001$) not to have flushed.

This long-term research programme continues with the ultimate aim of identifying genotypes suitable for producing timber in the UK. Crown closure is predicted by year 15 (2013) by which time thinning will become necessary. There is therefore a window of opportunity in the intervening years in which to conduct thorough research, both phenotypic characterisation and genetic variation studies, before some genotypes will be lost due to silvicultural needs within the trials.

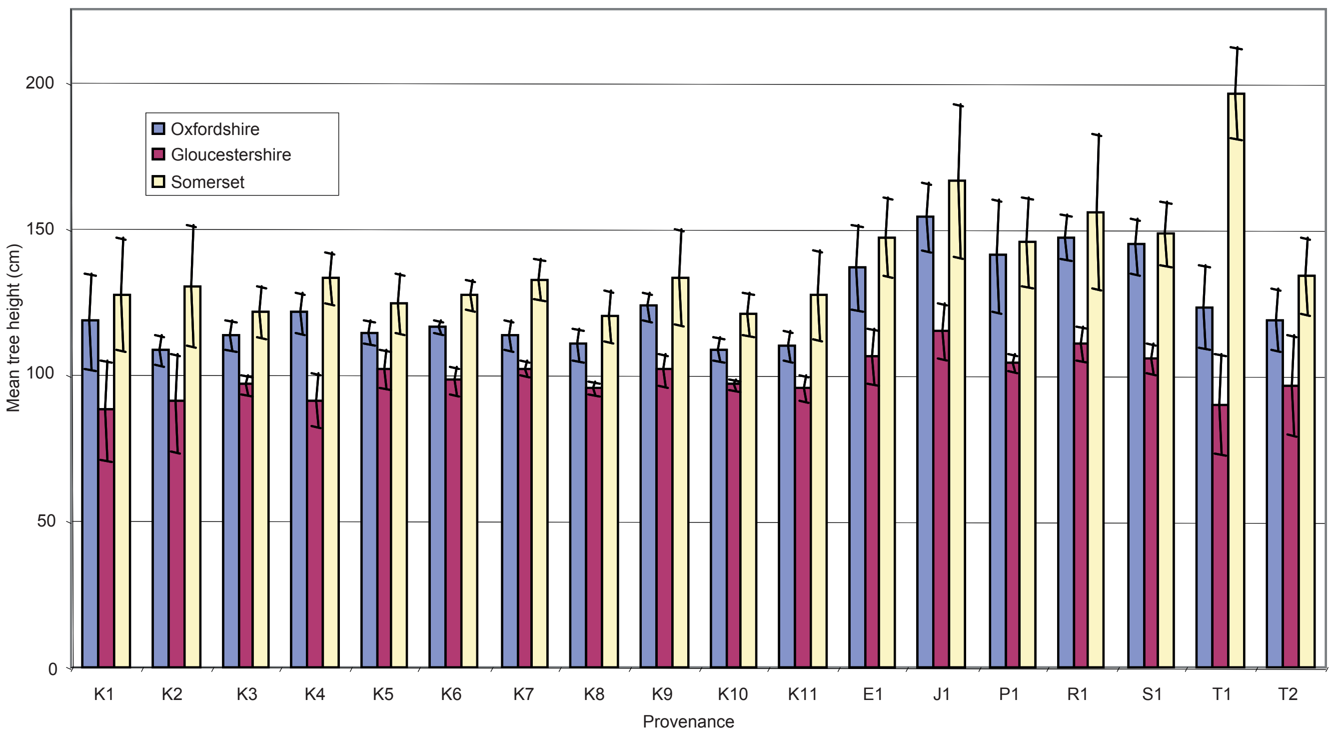

Figure 1.—Mean tree heights for provenances 1 – 18 in 2002, based on plot means within each of the field trial sites; Oxfordshire, Gloucestershire and Somerset. Provenance K stands for Kyrgyzstan (1 – 3 Ak-Terek, 4 Sharap, 5 Yaradar, 6 Shaidan, 7 Kyzyl-Ungur, 8 Katar-Yangak, 9 Kyok-Sarau, 10 Kyr-Sai, 11 Ters-Kolt), E1 Catalonia - Spain, J1 Tajikistan, P1 Karaj - Iran, R1 Romania, S1 Slovakia, T for Turkey (1 Trabzon, 2 Anatolia). Error bars show 95% confidence limits.

PLANTATION DESIGN

Walnuts in Britain are usually grown in pure stands or as individual trees, rather than in mixed plantations. Research conducted in the USA and Italy has indicated that walnuts can benefit from being planted in mixed stands, particularly with nitrogen-fixing species. Advantages may include increased growth rates and improvement of tree form, combined with protection from frost damage and reduced weed competition.

Background and Method

Common walnut is a light-demanding species and has the largest crown diameter, in relation to any given stem diameter, of the main timber-producing species used in British forestry (Hemery 2000). Traditionally in Europe it is usually recommended that common walnut is planted at very wide spacing, due to its intolerance to shading, unless the accompanying nurse species is very carefully maintained (MacDonald and others 1957, Evans 1984). Becquey (1997) recommended planting at 10 to 12 m for the common walnut but importantly, emphasized the importance of the genotype at such low densities.

There is however, increasing evidence that walnut may benefit when planted with suitable nurse or companion trees and shrubs. In the USA, Schlesinger and Williams (1984) tested black walnut in mixtures with black locust (*Robinia pseudoacacia*), autumn-olive (*Elaeagnus umbellata*) and alder (*Alnus glutinosa*). These species were chosen for their nitrogen-fixing (N-fixing) capabilities because many hardwood trees, including black walnut, have shown improved growth when grown with N-fixing species (Finn 1953). Autumn olive is a fast growing, multi-stemmed shrub reaching 6 to 9 m in height and wide-spreading (3.6 to 5.5 m), which is tolerant of exposure and will grow in most soil types in the UK (Bean 1950), and the most hardy of the Genus (Crawford 1998). Schlesinger and Williams (1984) demonstrated that walnut height growth improved with certain nurse species. Walnuts interplanted with autumn olive resulted in height gains of 56 to 351% over non-nursed walnuts. Campbell and Dawson (1989) calculated projections of growth that showed average DBH of 28 cm in 31 years for walnut inter-planted with the autumn olive. They projected that 40 years of growth would be required for the walnut to achieve 28 cm DBH with an alder nurse, or 80 years for those planted without a nurse.

In central Italy, mixed plantations with black walnut established in 1985, have also demonstrated impressive growth (Buresti and Frattegiani 1994). The first plantations with common walnut were established more recently, using nurses of cherry (*Prunus avium*), oleaster (*Elaeagnus angustifolia*), Italian alder (*Alnus cordata*) and robinia (Buresti 1995). Six year results indicated that walnut increased in height by 48% and stem diameter by 36% when planted with cherry (non N-fixing) compared to those walnuts with no nurse (Buresti 1995). However, walnuts with N-fixing nurses were 76% taller and average DBH was 42% greater than for pure-grown walnuts (Buresti 1995).

Research was initiated in 2000 with the aim of investigating planting mixtures that promote the growth of common walnut in UK, in terms of stem quality and vigor, leading to a reduction in rotation time (Hemery 2001). Several field trials were established in southern England, three with common walnut during spring 2000, and a large replicated trial with common, black and hybrid walnuts in 2002, to test the effects of growing these species with a number of companion species.

The trials include all combinations of the nurses (17): tree nurses only (4), tree + shrub nurses (12) and a walnut-only treatment (1). The trials were a randomized complete block (RCB) design, comprising 17 plots in each block (replicate), and two blocks per site. The walnuts were planted in a triangular pattern at approximately 5 x 5 m. At this spacing, based on a predicted crown diameter: stem diameter relationship for walnut (Hemery 2000), and a stem diameter increment of 1 cm year^{-1}, the onset of crown competition between walnuts would begin 15 to 20 years after planting. The tree nurse was planted at similar spacing between the walnuts in an alternative triangular pattern. Shrub nurses, where included, were planted in alternate rows, effectively surrounding the walnuts.

Results and Discussion

At the end of the second growing season walnut survival was high at 99.85%, with mortality only recorded at one site. No differences were recorded for height between sites or treatments at the end of the second of third growing seasons. At this early stage no effect from the nurse treatments would be expected although the observed impressive growth of the autumn olive and alder is predicted to have a positive effect on the walnut from the fifth growing season onwards.

DISCUSSION

The research programme described aims to build on the wealth of experience already gathered across the world in walnut growing for timber production. Walnut forestry in the UK is undergoing a revival of interest fuelled by the research programmes initiated in the country. Variation in performance has been demonstrated within existing widely planted genotypes and between those sampled within the novel research programme including Kyrgyz provenances. Several key common misconceptions relating to the difficulty of establishing walnut successfully have been laid to rest by this research, not least by the excellent survival reported in all the walnut trials described above. Phenology remains an important research area for the future, where the importance of selecting late-flushing phenotypes is paramount for successful walnut establishment, given the unpredictable spring climate in the UK. Future research must also address predicted climate change that might favour the silviculture of walnut species in the UK. Strategic consideration needs to be directed towards supplying the predicted increased demand for tested and quality-assured walnut planting stock for use in the UK. It is hoped that the combined silvicultural and genetic improvement research programmes will continue to encourage and foster a revival of interest in growing walnut in the UK.

ACKNOWLEDGMENTS

Woodland Heritage for supporting the establishment of the walnut nitrogen and companion planting trials and for sponsoring several overseas walnut field trips. Collaborative partners within the British & Irish Hardwoods Improvement Programme and overseas, including Istituto Sperimentale per la Selvicoltura (Italy) and Institute of Forest and Walnut Breeding (Kyrgyzstan). Direct support from The Royal Forestry Society, The National Forest Company, Nicholson Nurseries and landowners hosting external trials. Finally the trustees and patrons of the Northmoor Trust for their continued support.

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