Forestry Commission
231 Corstorphine Road
Edinburgh
EH12 7AT
www.forestry.gov.uk

Establishment and Management of Short Rotation Coppice

PRACTICE NOTE

BY IAN TUBBY & ALAN ARMSTRONG OF FOREST RESEARCH SEPTEMBER 2002

SUMMARY

This Practice Note reviews existing knowledge and gives guidance on site selection and preparation, plantation design, planting, weed control, crop management, pest management and yield for short rotation coppice plantations of willow and poplar grown as sources of renewable energy. Comprehensive references are included should readers require more information. Applicants to DEFRA's Energy Crop Scheme should also read *Growing short rotation coppice* available from DEFRA and ADAS offices.

INTRODUCTION

There is a growing consensus that CO_2 emissions from burning fossil fuels are altering the global climate. The UK government aims to reduce national CO_2 emissions by 20%, on 1990 levels, by 2010. Following the 1994 Declaration of Madrid, the EU aims to meet 15% of its real primary energy demand with energy produced from renewable sources again by 2010.

The use of willow and poplar short rotation coppice (SRC) as an energy source could help meet these targets. SRC crops can provide a renewable energy source that produces very low net CO_2 emissions and low levels of nitrogen and sulphur pollutants (Patterson, 1994; Matthews and Robertson, 2001). In addition to these benefits, SRC crops require a reduced chemical input when compared to conventional arable crops, can provide an alternative use of agricultural land and can enhance the local environment through increased biodiversity.

The establishment of SRC plantations has more in common with agricultural or horticultural crops than forestry. Ground preparation is carried out using conventional agricultural machinery and methods. Generally, the crop is planted by simply pushing cuttings, approximately 20 cm long and 1 cm in diameter, into the cultivated soil. Shoots and roots quickly develop from these cuttings. Typically two or three shoots sprout from each cutting and grow between two and three metres in the first growing season. Traditionally in the UK, this growth is cut back after one growing season to just above ground level. This encourages the developing coppice stool to produce more shoots in the following year. These shoots are then left to grow on for between 2 and 4 years before being harvested with specialised machinery. The stool is left in the ground and produces more shoots that grow for a further 2 to 4 years until the next harvest. Several 2 to 4-year cutting cycles take place before yield declines and the crop is replaced; the exact length of time the stools remain in the ground depends on their productivity and the wishes of the landowner.

Much of the information contained in this Note is based on results emerging from the 'Yield Models for Energy Coppice of Poplar and Willow' project which is jointly funded by the Forestry Commission (FC), Department of Trade and Industry (DTI) and Department for Environment, Food & Rural Affairs (DEFRA). Work for this project is carried out by the staff of Forest Research and the Department of Agriculture and Rural Development, Northern Ireland (DARDNI). Forty-nine SRC research trials planted on a wide range of soil types across England, Wales, Scotland and Northern Ireland form the basis of this project. Data from these sites are being used to evaluate the performance of a range of willow and poplar varieties against site characteristics (Armstrong, 1997). At the time of writing these sites are in their second 3-year cutting cycle. This project is referred to as the 'site/yield project' throughout this Note.

THE SITE

Site selection

Climate

The crop can tolerate a range of climatic conditions but areas with low soil moisture availability should be avoided otherwise yield will not be maximised. In low rainfall areas water conservation should be considered before planting. Studies have shown that water yield can be reduced by as much as 50% if SRC is planted instead of a grass or arable crop (Hall *et al.*, 1996).

Soil conditions

SRC can be grown successfully on a wide range of soil types but very wet or very dry soils are best avoided. Very gravelly soils that drain quickly are generally unsuitable for SRC as the coppice will not have an adequate water supply. SRC should not be planted on soils that remain waterlogged for much of the year because cuttings planted into waterlogged soils are unlikely to root successfully and boggy ground will hamper harvesting operations which are generally carried out in the winter. Steep slopes will hinder mechanised planting and harvesting.

Ideally SRC should be grown on a medium textured soil which is aerated but still holds a good supply of moisture. Results emerging from the site/yield project suggest that heavier brown earths with a high clay content, and often gleyed below 40 cm, are well suited to SRC. Ex-pasture sites can be productive, perhaps due to the ploughed-in turf releasing nitrogen and retaining moisture as it rots down. Soils should be well cultivated to give a rootable depth of 30 cm or more.

SRC is very good at taking up nitrogen and is ideal for tackling nitrate pollution in Nitrate Sensitive Areas or Nitrate Vulnerable Zones. Nitrate and pesticide levels in groundwater beneath SRC are generally much lower than beneath fertilised grassland or arable land due to high uptake by the SRC crop (Elowson and Christersson, 1994) and reduced chemical inputs. SRC can also be planted along lower field margins and riparian zones to act as a buffer for retaining diffuse pollutants draining from adjacent agricultural land. In Sweden, due to its high nitrate uptake, SRC has established a role in the treatment of waste water and landfill leachate (Aronsson *et al.*, 2000; Aronsson and Bergström, 2001). Despite this ability to take up nitrates, on most soils nitrogen will not be a limiting factor for an SRC crop. Exceptions may include very light soils where nutrient leaching takes place.

Soil pH should ideally fall in the range 5.5–7.5 for poplar (Jobling, 1990) and 5.5–7 for willow (Carter, personal communication, 2002) although results from the site/yield project suggest that there are varieties of willow and poplar tolerant to soil pH outside these ranges.

Landscape

It is important to bear in mind that at the end of a 3-year cutting cycle the SRC crop may be up to 8.0 m in height. It is therefore important to consider the impact this will have on the landscape and to incorporate forest design principles at the early planning stages as these may restrict the size of the area to be planted. SRC must conform to the UK Forestry Standard including landscape design. Guidance on SRC landscape design can be found in Forestry Commission Guideline Note 2 *Short rotation coppice in the landscape* (Bell and McIntosh, 2001).

Archaeology

The establishment of SRC should conform to the UK Forestry Standard regarding heritage features and the protection of archaeological sites. Ploughing, sub-soiling and root growth can damage archaeological sites and deposits. SRC should not be located on sites of archaeological importance including areas with potential for waterlogged deposits. Care should be taken to ensure that crop growth does not affect the setting of sites. Guidance can be found in the *Forests and archaeology guidelines* (Forestry Commission, 1995d).

Biodiversity

The habitat created by an SRC plantation is very different to those found within conventional agricultural crops. Willow and poplar support a large number of insect species most of which cause little damage to the crop. Many songbird species are attracted to SRC, especially willow plantations. Some migrant warbler species that are becoming less common elsewhere are often seen in stands of SRC willow. Shade tolerant plants may become established under the dense crop canopy while headlands and access rides can provide a ‘woodland edge’-type habitat where flowering plants may thrive. Before applying pesticides to the crop their possible impact on this biodiversity should be carefully considered. Pesticides should not be used as a matter of course when only low levels of damage are observed. Large-scale SRC plantations may have a negative impact on local populations of birds dependent on open farmland. The Game Conservancy Trust is currently monitoring biodiversity within commercial SRC plantations.

Site preparation

A high standard of site preparation is essential to maximise yield and produce a uniform, easily managed crop. Operations should only be carried out when the soil is dry enough to allow machinery onto the ground without compacting the site.

Subsoiling

Ex-arable sites may have a plough pan, or soil compaction problems, that could restrict root development. A soil pit should be dug to examine the extent of compaction. Any compaction should be relieved by subsoiling, carried out when the soil is dry enough to maximise shattering and minimise soil damage.

Cultivating

The site should be ploughed in the late autumn or early winter to 30 cm and left to over-winter in this state to allow frost to break the soil down further. A fine tilth is required for ease of planting, to aid the formation of a healthy root system and for the effective use of residual herbicides. To achieve this it is recommended that a power harrow is used immediately before planting. Power harrowing is preferred to rotovating as it keeps moisture, which has accumulated over winter, in the rooting zone whereas rotovation tends to bring moisture from the main rooting zone to the surface, replacing it with dry surface soil.

Control of leatherjackets

On sites that have been used as pasture or setaside for a number of years there is a potential problem of root grazing by leatherjackets, the larvae of craneflies *(Tipulidae)*. The adults lay their eggs in grassy swards; if the sward is ploughed in and planted with SRC, the only food source available to the leatherjackets is the newly emerging roots and shoots from the coppice cuttings. If this is anticipated a single application of an insecticide may be required. It is preferable to apply the insecticide before planting to avoid crop damage. Leatherjackets are not usually a problem after the first year of establishment.

Protection from mammals

Both willow and poplar are very palatable to a range of mammals. Rabbits and hares, in particular, can cause serious damage soon after planting. Deer are another threat during crop establishment although they usually do little damage to a mature plantation. Voles can girdle young stems but are usually only a problem if the site is weedy and offers them suitable cover.

Protection against rabbits and deer can be provided by wire mesh fencing suitably dug in to deter rabbits from burrowing underneath (Pepper, 1998). This is an expensive operation and the fence will need regular inspection to maintain its integrity. Temporary, reusable fencing, made of lightweight wire or high tensile plastic shows great promise for coppice protection with potential savings of 25% compared with the cost of more traditional post and wire fences.

Electric fencing can be installed but this also needs regular inspection to ensure that weeds do not short it out. It should only be considered as a temporary measure (Hodge and Pepper, 1998). Electric fencing is less effective in the presence of high numbers of rabbits, where it will only exclude 90% of individuals present, and if power failure occurs rabbits will soon gain access.

Poplar trees are often attacked by squirrels but this has not yet proved to be a problem in SRC. Damage risk will be dependent on the proximity of other woodland suitable for holding resident grey squirrel populations, but crops are unlikely to be vulnerable to damage in the first 2 years after planting. There has been only one recorded incidence of minor squirrel damage across the 49 site/yield research sites in the last 6 years.

ESTABLISHMENT

Plantation design and spacing

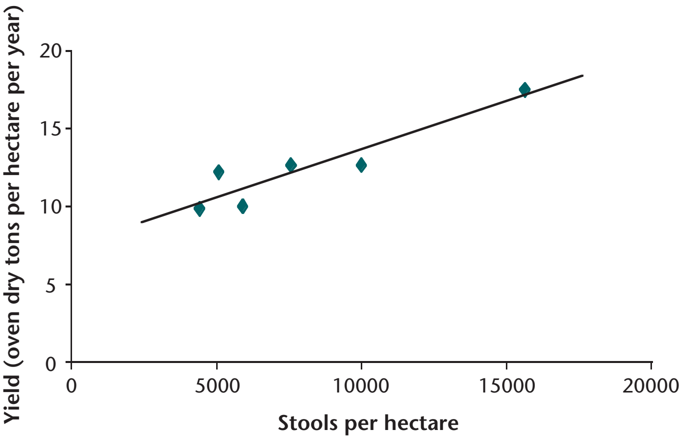
Before planting, it is important to plan for harvesting and to select a planting design that will be compatible with the harvesting system (Forestry Commission, 1995a). In the past, trial plantings have used a square planting design as this maximises use of space and there had been no need to consider machinery needs. Today the Swedish twin row or rectangular design is favoured. Research in Sweden (Verwijst, personal communication) has shown that this rectangular planting design does not adversely effect yield. Further details on plantation design considerations are included in *Growing short rotation coppice* (DEFRA, 2002).

Planting densities have increased over the last decade. This move is supported by research carried out by Armstrong and Johns (1997) who found that first harvest yield increased as planting densities increased from approximately 4500 stools per hectare up to 15 625 per hectare (ha^{-1}). The results for *Salix viminalis,* 'Bowles

Hybrid', are shown in Figure 1. This trend was repeated in the other willow variety and both poplar varieties tested. Cuttings were planted on a square spacing design. Yield was assessed at the end of the first 3-year cutting cycle.

Figure 1

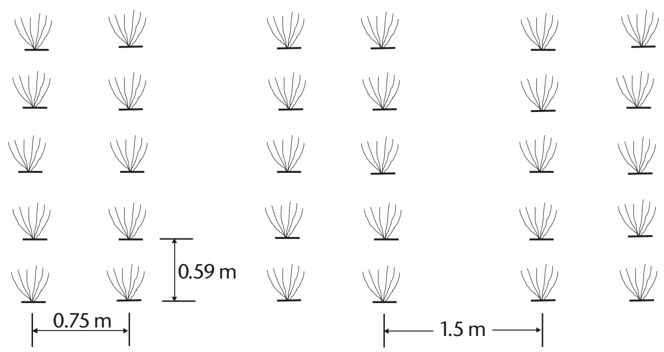
Yield against planting density



More recent work investigating the effect of harvest frequency and planting densities (from 8625 to 111 000 stools ha^{-1}) on yield suggests that a figure of 15 625 stools ha^{-1} offers the best economic return over the lifetime of the crop (Bullard *et al.*, 2002).

At present, most commercial willow crops in Britain are established at a spacing of 0.75 m between rows and 1.5 m between twin rows with 0.59 m between cuttings to give a stocking of 15 000 cuttings ha^{-1} (illustrated in Figure 2).

Figure 2 **Recommended planting design**



Plant material and handling

A range of tree species and varieties have been tested for suitability as SRC energy crops (Potter, 1990). Willows and poplar hybrids emerged as the most suitable for a number of reasons. Poplar varieties are controlled under the Forest Reproductive Material (FRM) Regulations. Willow and poplar varieties currently recommended and approved for SRC plantations are listed in Forestry Commission Information Note 17 (Tabbush *et al.*, revision in press). These varieties have proven to grow well when exposed to UK pest, disease and climate conditions. The list is updated as information on new varieties becomes available and should be consulted before selecting planting material. Plant material for varieties covered by Plant Variety Rights legislation may not be reproduced for planting or sale without permission from the plant breeder.

Stock quality is important and planting material should be bought from a reputable source. Willow is generally supplied as 2–3 m long rods. These are either automatically cut into 20–25 cm lengths by the step planter or can be used whole with the layflat planter. Shorter cuttings must be used in conjunction with machines based on cabbage planters; cuttings are normally 20–25 cm long with a diameter of 10–20 mm at their midpoint. Poplar cuttings should have a healthy bud about 1 cm below the top cut; this does not apply to willow cuttings as they can produce shoots along the length of the cutting.

Rods and cuttings are generally taken between December and March, when buds are fully dormant, and must either be planted immediately or carefully stored in cool conditions until they are used. Once buds have started to burst cuttings will not root easily and should not be planted. Unprotected planting material is very vulnerable to moisture loss through the exposed cut surfaces. Planting material must never be left in direct sunlight or in a warm environment, such as an office, as stock will be damaged or killed by desiccation. Protect planting material by placing it in sealed, labelled, polythene bags to prevent water loss, and store them at –2 to –4°C. Planting material stored at this temperature will remain viable for several weeks to accommodate delayed planting. Cuttings can also be stored temporarily outside in a shady location by placing them upright and covering them in moist, coarse sand. Always inspect the rods and cuttings regularly during storage to ensure that they have not started to produce roots and shoots.

Planting

Planting with freshly cut material should take place in early spring (February to March), if soil conditions allow. This gives the cuttings the entire growing season in which to become established. If the soil is waterlogged, planting should be delayed until the ground is fit for cultivation and a good tilth has been produced. After the end of March, planting is still possible using cuttings from a cold store; planting has been successful on both commercial and research plots using cold-stored material as late as June. If this coincides with favourable soil and weather conditions, satisfactory establishment is possible. Autumn planting is not proven and should be avoided until the results from ongoing research are available. It is likely that planted cuttings may fail to root if the ground becomes waterlogged over winter.

For commercial planting of willow it is standard practice to use machines such as the Salix Maskiner 'Step Planter'. This machine has been designed to make use of 2 or 3 m long willow rods which are cut into 20 cm lengths by the machine immediately before planting. This keeps water loss from the cutting to a minimum. The step planter is not recommended for use with poplar because the point of cut cannot be constrained to leave a prime bud near to the tip of the cutting. Modified cabbage planters or similar machines are available that are capable of planting pre-prepared cuttings (Forestry Commission, 1994a).

The Autstoft planting machine, which uses smaller cuttings of willow drilled into a shallow furrow, has returned the lowest unit cost but in a very dry year the shallow planting depth may result in mortality through desiccation (Forestry Commission, 1995b). Research carried out in Northern Ireland has shown that planting billets may result in poor growth during the establishment period.

Border Biofuels Ltd, in conjunction with Hvidsted Energy of Denmark, have developed a 'lay flat' planting system. The lay flat system plants twin rows of 2 or 3 m long rods lying horizontally, end to end, just under the soil surface. Shoots and roots develop from the buried rod. The frequency of shoots appearing along the rod cannot be controlled but the distance between the twin rows can. Initial trials using willow planting material have been established. The lay flat principle is also being tested with poplar planting material.

As mentioned previously, there is an additional potential problem with early planting and that is one of reconsolidation of the soil prior to the start of root growth. Preparing planting material for a mixture of varieties may take longer than if only one variety is to be planted. The potential advantages of planting a mixture of several compatible SRC varieties are detailed in the 'Pests and diseases' section. Hand planting can be too costly for large SRC plantations.

PROTECTION

Weed control

It is not possible to overemphasise the importance of establishing an SRC crop in completely weed-free conditions. Willows and poplars are intolerant of weed competition, and even low levels of weed cover will cause uneven growth and greatly reduced yields. A completely weed-free site is required at planting and must be maintained until the crop foliage shades out the weeds. The choice of suitable products will depend on the range of weed species anticipated and reference to Forestry Commission Field Book 14, *Herbicides for farm woodlands and short rotation coppice* (Willoughby and Clay, 1996) is recommended. A greater range of products is available for SRC than for conventional forestry.

Weed control can be divided into three phases: before cultivation, shortly after planting and after cut back or harvesting. All perennial weeds should be sprayed with a broad spectrum contact herbicide such as glyphosate before any cultivation takes place. Once the crop has been planted and the soil has been consolidated, e.g. with a Cambridge roller, to form a firm fine tilth, residual soil-acting herbicides should be applied to control germinating weeds. A rapid and profuse growth of highly competitive weed species is to be expected on fertile sites after cultivation, so the use of appropriate residual herbicides is essential to maximise SRC survival and early growth.

Given good post-planting weed control, crops should remain clear for most of the growing season. Elsewhere control of established weeds is difficult without using directed sprays, but grasses can be safely controlled using cycloxydim, propaquizafop or fluazifop and compositae weeds by clopyralid. After cut back at the end of the first growing season the crop should be sprayed with a contact herbicide mixed with a residual herbicide to control both established and subsequently germinating weeds. A tank mixture of amitrole and pendimethalin has proven successful in controlling existing weeds and provides a good residual effect in commercial SRC plantations. Simazine has been used in the past but is not recommended as severe crop damage has been sustained in some instances. Field Book 14 (Willoughby and Clay, 1996) lists the most appropriate products for a given weed population. The dense canopy of a vigorous SRC crop should shade out most weeds once the crop has become established. Subsequent weeding should only be required after harvesting.

Pests and diseases

Willows and poplars are host to a wide range of fungal pathogens and leaf-eating insects. Using current recommended varieties is a good defence against these diseases and pests. 'The European Willow Breeding Partnership', comprising IACR-Long Ashton Research Station, Svalof Weibull and Murray Carter, has the objectives of breeding new vigorous varieties with increased resistance to insect damage, browsing animals and rust (Lindegaard and Barker, 1997). A poplar breeding programme in Geraardsbergen, Belgium seeks to produce vigorous and disease-resistant varieties.

A relatively high level of leaf damage can be tolerated by SRC with little adverse effect but severe or repeated attacks will reduce yield. For example, removal of 30% of leaves had little effect on yield whereas removal of 90% of leaves in June and August reduced yield by 40% (Kendall *et al.,* 1996). In extreme cases leaf loss may cause crop death, and this has been observed in both poplar and willow.

The most important insect species that affect willow and poplar are beetles of the chrysomelid family, mainly brassy and blue willow beetles (*Phratora* spp.). There are many insecticides currently available that will control willow beetles but their overall application to coppice is difficult, environmentally undesirable and probably uneconomic. However, it has been suggested that using limited and targeted quantities of insecticide as an 'emergency control measure' may be acceptable under some conditions (Tucker and Sage, 1999). From the early results of the site/yield project it seems that beetle populations fluctuate between years and that sites attacked by large numbers of beetles one year do not necessarily continue to suffer high levels of damage in following years.

Melampsora rust is the most important fungal pathogen of both willow and poplar. Willow is susceptible to a number of different species of rust, of which *Melampsora epitea* is the most important in the UK. The main rust affecting poplar crops is *Melampsora larici-populina* although *Melampsora allii-populina,* a species with a mainly southern European range, occurs in southern Britain during unusually warm summers.

Different varieties of willows and poplars have different degrees of susceptibility to the various species and races of rust. The pathogenicity and specificity of these rusts change over time, so it is impossible to guarantee that SRC varieties currently resistant, or less susceptible, to rust infection will remain so in the future. Advice should be taken from Forest Research, IACR-Long Ashton or DARDNI as to which varieties are currently most tolerant to rust.

Recommendations based on research in Northern Ireland (McCracken and Dawson, 1997) advocate planting mixtures of five or six varieties to limit rust infection. Results emerging from site/yield experiments with SRC varieties planted in both mixture and monoclonal plots have been variable. The experiments contain row by row mixtures of three poplar or three willow varieties grown alongside monocultural, or 'pure', plots of the same varieties. One poplar variety suffered a significantly higher level of rust infection when grown as part of a mixture rather than as a monoculture (Straw and Lonsdale, 2000; Armstrong *et al.,* 2000). This is possibly a result of exposure to high levels of the pathogen present on the more susceptible varieties in the mix. Levels of rust infection on the remaining two poplar and three willow varieties showed no significant differences between the mixture and 'pure' plots. Mixtures are likely to be most effective in limiting rust infection if the component varieties are not susceptible to the same race, or races, of rust attacking the crop.

Establishing large plantations of a single, currently resistant, high-yielding variety to maximise financial return in the short term is a high-risk strategy and not recommended. There are examples of resistant SRC varieties becoming susceptible to rust as the number and abundance of races making up the natural rust population have evolved. In extreme cases this has led to certain varieties suffering high levels of mortality across the country as resistance has failed and the population of the new, virulent, race of *Melampsora* has increased. This sequence of events is very dynamic – changes in the composition of the rust population can occur in just a few years, and may be influenced by the abundance of susceptible host species in the environment. This is an important point since the working life of an SRC plantation is expected to be at least 15 years and replanting is an expensive operation.

Recent work on SRC mixtures containing up to 20 varieties from a diverse genetic background has shown that surviving components of mixed plantations can quickly occupy the spaces left by dead stools and more than compensate for the losses incurred by disease or other factors (McCracken *et al.,* 2001). Adopting a strategy of planting intimate mixtures of several varieties is currently the recommended method of limiting economic losses caused by rust infection.

Ideally these mixtures should contain a selection of varieties with different rust tolerance characteristics, referred to as different 'mix codes'. Information on the characteristics exhibited by different varieties is available in the revised Forestry Commission Information Note 17 *Poplar and willow varieties for short rotation coppice* (Tabbush *et al.*, 2002). This publication is updated regularly as new varieties are tested and results become available. Currently many high-yielding varieties are classified as 'mix code A' with the result that many plantations have been established with a mixture of varieties solely of this type. This is not thought to offer the same level of protection against rust as planting varieties with different mix codes in the same plantation. The interactions taking place within plantations containing a mix of similar varieties are currently being monitored (McCracken *et al.*, 2001).

In addition to offering some protection against rust, planting a carefully selected random mixture of varieties can lead to a reduction in damage caused by *Phratora vulgatissima* beetles (Peacock and Herrick, 2000).

CROP MANAGEMENT

A planning schedule covering the timing of various crop management activities is included in *Growing short rotation coppice* (DEFRA, 2002).

Cut back

It is standard practice to cut back growth from willow stools at the end of the first year to encourage the formation of multi-stemmed stools in the following growing season. This can be carried out cheaply using conventional agricultural equipment. Vigorous growth following cut back captures the site quickly and reduces the need for continued chemical weed control.

Although not standard practice, there may be a case for not cutting back when the crop has grown so well in the first year after planting that there are enough healthy stems on each stool to shade out weeds and provide the basis for good growth in subsequent years.

As a rule poplar crops do not respond to cut back in the same way as willows. Many poplar varieties on the market show very strong apical dominance and even after cut back only produce one or two main stems. This may not be enough to shade out weed competition and the crop may require additional herbicide treatments. Under these circumstances there may be an advantage in delaying cut back, or even growing the crop as single stem until the first harvest.

Cutting cycle

Short rotation coppice is harvested after leaf-fall and before bud burst. Traditionally SRC has been grown on a 2 to 4-year cutting cycle. There are no hard and fast rules for cutting cycle length. Ideally decisions should be made on a site by site basis bearing in mind the following points:

- **Management objectives and cash flow**

  While the main reason for growing SRC is to achieve a financial return, other benefits such as increased biodiversity, use as a shelter or screen or as game cover may influence the timing and pattern of harvesting. This may lead to harvests having to be made outside the 2 to 4-year bracket mentioned above.

- **'Site capture'**

  For a crop to put on maximum biomass its leaf canopy must intercept as much solar radiation as possible. Sunlight hitting bare soil through gaps in the canopy is effectively wasted energy. The time taken for a crop to achieve a 'closed' canopy will depend on the species and variety planted, the planting density and site conditions. On a good, fertile site with favourable weather a vigorous variety may achieve a closed canopy after 2 years of its first cutting cycle. On a poorer site the same variety planted at the same spacing may take 3 or 4 years to close canopy. Results emerging from the site/yield project suggest that on fertile sites vigorous willow varieties put on large amounts of growth in years 1 and 2 and reduced amounts of growth thereafter. This could be due to the crop closing canopy quickly and growing rapidly before competition for resources between stools slows growth down in the third year. In such cases a 2-year cutting cycle would be ideal. Conversely research carried out on poplar varieties suggests that this species performs better on longer rotations. Growing poplar SRC on a single 4-year cutting cycle increased yield by up to 70% when compared with the sum of the yield from two 2-year cutting cycles (Armstrong, 1996; Armstrong *et al.*, 1999). Poplar coppice stools tend to produce fewer, straighter, heavier stems compared to willow SRC. This means that poplar is less likely to capture the site in the first year of the cutting cycle, resulting in low annual yield increments in the first 2 years of the rotation before putting on large increments in years 3 and 4.

Fertiliser requirements

The production of inorganic fertilisers relies heavily on the use of fossil fuels. When these products are used on SRC the carbon and energy budgets of the crop are altered. Each application of inorganic fertiliser in effect increases both the amount of energy consumed by the SRC system and the amount of CO_2 and other pollutants emitted. Furthermore, the application of inorganic fertiliser is an additional cost for the grower to bear. If the crop responds by producing enough fuel wood to offset the energy used and cost incurred then use of artificial fertiliser may be environmentally and financially justified. Research has shown that a positive response to fertiliser application is not guaranteed. Work carried out by Yorkshire Environmental Limited (1996), investigating the performance of fertilised SRC, showed that treating the crop with sewage sludge or inorganic fertiliser did not significantly increase yield compared to unfertilised crops over the first few years of the plantation's life. This may have been due to the naturally high fertility of the site. Other studies have shown increased yield as a result of fertiliser treatments.

As the crop is harvested after leaf fall, nutrients contained in the foliage are recycled back into the soil. Only nutrients in the harvested coppice stems are removed from the site. Leaf litter turn over and atmospheric nitrogen inputs will compensate for a large amount of the nutrients removed. Potter (1990) reported that up to 135.5 kg yr^{-1} of nitrogen, 15.8 kg yr^{-1} of phosphorus and 85.1 kg yr^{-1} potassium were being removed by the stems of SRC crops producing over 10 oven dry tonnes per hectare per year (odt ha^{-1} yr^{-1}). Potter concluded that it is unlikely that this level of nutrient removal would limit SRC performance on a typical site in the short term. Poor quality soils may need additional inputs to maintain good yields. New, higher yielding SRC varieties may remove larger quantities of nutrients and require greater fertiliser inputs. Soil fertility should be monitored to assess the need for fertiliser treatments throughout the plantation's life in order to keep costs incurred by the grower to a minimum and the crop performing at its best. Applying fertiliser to a standing crop of SRC may be difficult although specialised machinery has been developed in Sweden (Danfors *et al.,* 1998).

An alternative to inorganic fertiliser is sewage sludge or livestock slurry. Cattle slurry has been shown to significantly improve yields of SRC growing on low quality soils (Heaton, 2000). Slurry may also act as a mulch, suppressing weeds and retaining moisture. SRC provides a good outlet for what is generally regarded as a waste product. As SRC is generally grown on land that may be used for food crops in the future, the level of heavy metals introduced to the site by using organic fertiliser should be monitored.

Research investigating the effects of fertilisers on SRC crops is currently being carried out by DARDNI. More information on fertilising SRC crops is available in *Growing short rotation coppice* (DEFRA, 2002). Information on mineral deficiencies in SRC is also available in the same publication.

Harvesting machinery

A desk top study was carried out by Forest Research Technical Development Branch in 1994 to identify suitable harvesting machines for evaluation (Forestry Commission, 1994b). Following this study two field trials were established in January 1994 and December 1994 (Forestry Commission, 1994c, 1995c) to evaluate the selected machines.

There are two basic harvesting systems that can be used with SRC. The crop can be cut and chipped in one operation, or the crop can be cut and the stems left intact to air-dry, with chipping carried out as a separate operation at a later date. Harvesters that do not chip the stems are known as 'stick harvesters'. Most of the machinery tested takes advantage of the twin row design and is capable of cutting two rows in one pass; where possible output can be maximised by using two way working. Cut and chip machines tend to work more efficiently for the landowner. In the trials, the Claas Jaguar fitted with a blade modified for harvesting SRC came out as best of the cut and chip machines although the Austoft and the Salix Maskiner returned a similar profit to the grower. Chips produced by this type of machine need to be stored carefully to avoid decomposition and reduced quality. Current work is examining economic methods of storage and drying. The Empire 2000 was assessed as best of the stick harvesters (Forestry Commission, 1996) but new stick harvesters are currently under development. Billet harvesters are intermediate between the stick harvesters and conventional cut-and-chip machines. These machines cut coppice stems into shorter lengths, or billets. Due to increased air flow through piles of billets, compared to wood chips, some of the storage problems associated with smaller chips are avoided. As this industry is still in its infancy, machinery is constantly evolving and up to date information should be sought on the current stage of development and the specification of wood chips required by power plants.

YIELD – EARLY RESULTS FROM THE SITE/YIELD PROJECT

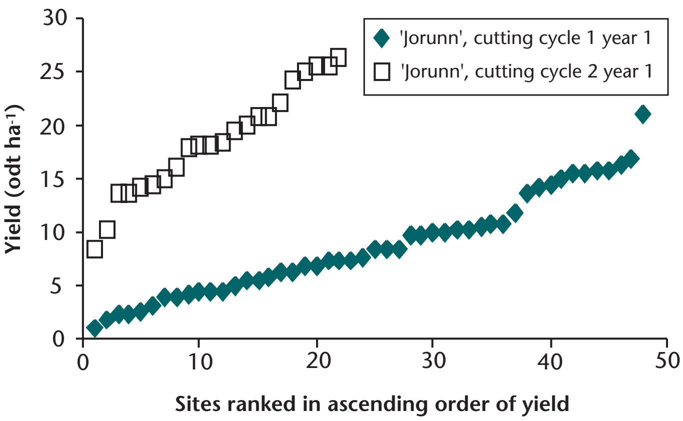
Yield estimates from the site/yield project are calculated annually. Sites are spread throughout England, Scotland, Wales and N. Ireland, covering a wide range of soil and climate types. Although these results are currently provisional they provide an insight into how SRC performs over time.

Willow yield

In the first year of the first cutting cycle willow yields as high as 21 odt ha^{-1} yr^{-1} were recorded. At the other end of the scale some varieties at some sites suffered very high mortality. This variation in performance between sites can be seen in Figure 3. The average yield obtained for 'Jorunn' across 48 sites at the end of the first 3-year cutting cycle was around 8.8 odt ha^{-1} yr^{-1}. This is similar to yield achieved on commercial sites. With current funding arrangements, growers consider that SRC needs to grow at around 10 odt ha^{-1} yr^{-1} to provide a reasonable economic return. In this light the average yield mentioned above does not seem favourable. However, these yields were returned from trials or plantations planted at 10 000 or 12 000 stools ha^{-1}. Since then the industry has adopted higher planting densities which should lead to improved yields. Furthermore, yield in the second and subsequent cutting cycles is likely to increase considerably as the coppice stools become fully established. Data collected from 21 sites in the first year of the second 3-year cutting cycle still exhibit considerable variation from site to site but average yield has increased to 18.22 odt ha^{-1} yr^{-1} (Figure 3). In these trials 'Jorunn' was regarded as an 'average' willow variety offering reasonable performance on a variety of sites.

Figure 3

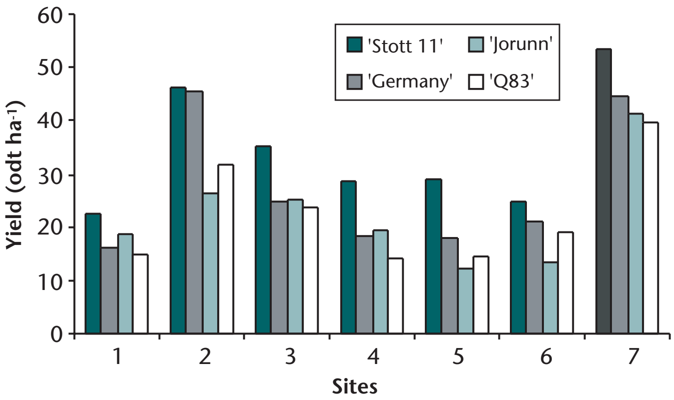
Chart showing standing biomass (odt ha^{-1}) for 'Jorunn' after 1 year in the first cutting cycle (data from 48 sites) and after 1 year in the second cutting cycle (data from 22 sites)



Breeding programmes continue to produce varieties that outperform older varieties such as 'Jorunn'. This is clearly seen in Figure 4 where the experimental variety 'Stott 11' is compared with three older varieties growing at the same sites. 'Stott 11' is the best performer in each case.

Figure 4

Performance of 'Stott 11' against older willow varieties at 7 sites, standing biomass (odt ha^{-1}) after first 3-year cutting cycle



Poplar yield

Although poplar is not currently used as a commercial SRC crop it can produce good yields on suitable sites. At the end of the first 3-year cutting cycle the poplar variety 'Trichobel' outperformed the willow benchmark, 'Jorunn', at 18 out of 48 sites. At eight sites yield achieved by the two varieties was very similar and at the remaining 22 sites 'Jorunn' out-performed 'Trichobel'. At two sites in Northern Ireland all three poplar varieties present outperformed their three willow counterparts. At one of these sites planting 'Trichobel' instead of 'Jorunn' increased estimated yield from around 24 odt ha^{-1} to over 40 odt ha^{-1} at the end of the first 3-year cutting cycle. Conversely at a site in East Anglia 'Jorunn' produced 22 odt ha^{-1} while 'Trichobel' struggled to produce 4 odt ha^{-1} after 3 years' growth. Even sites that are only a short distance apart may produce very different yields when planted with the same varieties. Table 1 summarises results obtained at two sites in the East Midlands of England planted on different soil types. At Dunstall Court all three willow varieties produced 30 odt ha^{-1} or more while the poplars produced 21–24 odt ha^{-1} over the same 3-year period. This was reversed at the Harper Adams site where poplars outperformed willows. These figures highlight the fact that matching species and variety to site conditions is essential if growth is to be maximised. Work at the University of Southampton is currently investigating the suitability of a selection of new poplar varieties for use in SRC systems.

Table 1

Comparison of poplar and willow yields obtained at two sites in the East Midlands of England after one 3-year cutting cycle

Site	Species	Variety	Standing biomass odt ha^{-1} year 1	Standing biomass odt ha^{-1} year 2	Standing biomass odt ha^{-1} year 3
Harper Adams	Poplar	'Trichobel'	11.91	23.23	41.71
Harper Adams	Poplar	'Beaupré'	15.87	24.70	36.54
Harper Adams	Poplar	'Ghoy'	14.62	22.89	35.89
Harper Adams	Willow	'Jorunn'	14.89	22.39	33.33
Harper Adams	Willow	'Germany'	7.71	12.52	22.01
Harper Adams	Willow	'Q83'	19.16	22.97	34.06
Dunstall Court	Poplar	'Trichobel'	4.90	11.60	23.68
Dunstall Court	Poplar	'Beaupré'	7.29	12.24	21.31
Dunstall Court	Poplar	'Ghoy'	7.48	13.91	23.76
Dunstall Court	Willow	'Jorunn'	21.15	26.51	36.61
Dunstall Court	Willow	'Germany'	9.50	20.12	30.47
Dunstall Court	Willow	'Q83'	11.16	20.34	30.85

Site reinstatement

Coppice stools need to be removed or allowed to rot before an SRC plantation can be cultivated, ready for the next crop. Harvesting the stems and applying herbicide to the subsequent regrowth before ploughing up the stools is a method that has been used by commercial growers to remove willow SRC (Carter, personal communication, 2002). This is a cheap method of removing the crop but may not work as well on poplar stools which tend to root to a greater depth than their willow counterparts. Removing the stools with a large excavator has been tried but costs are high. Powerful forestry mulchers used for breaking up brash, undergrowth, stumps and scrub may be suitable for removing coppice stools. Other systems for crop removal are currently under investigation. SRC coppice may also damage land drains; these may need replacing if conventional arable crops are to be planted.

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USEFUL ADDRESSES

Short rotation coppice plantations may be eligible for grant aid under the Energy Crops Scheme (ECS) run by DEFRA in England. Applications for this scheme are administered by the DEFRA office at Crewe. Details can also be found on the DEFRA England Rural Development Programme website: www.defra.gov.uk/erdp/erdphome.htm

DEFRA
Electra Way
Crewe
Cheshire
CW1 6GL
Tel: 01270 754000
Fax: 01270 754275

ADAS offer advice to growers establishing SRC and other energy crops and their best practice guidelines should be read by applicants to DEFRA's Energy Crop Scheme.

ADAS Arthur Rickwood
Mepal, Ely
Cambs CB6 2BA
Tel: 01354 692531
Fax: 01354 694488

In Scotland, Wales and Northern Ireland financial help towards establishing an SRC plantation may be obtained under the Woodland Grant Scheme (WGS) available from the Forestry Commission. Details can be obtained from your local conservancy office or contact your national office. In Northern Ireland contact the Forest Service. Information on the WGS is also available on the Forestry Commission website: www.forestry.gov.uk

Forestry Commission
National Office Scotland
231 Corstorphine Road
Edinburgh EH12 7AT
Tel: 0131 3146156
Fax: 0131 3146152

Forestry Commisssion
National Office Wales
Victoria Terrace
Aberystwyth SY23 2DQ
Tel: 01970 625866
Fax: 01970 626177

DARDNI/Forest Service
Dundonald House
Upper Newtownards Road
Belfast
Tel: 028 90520100
Fax: 028 90524570

The DTI's Renewable Energy Programme supports energy crops research and development. For further information, and copies of publications, contact:

Renewable Energy Helpline
Future Energy Solutions
Harwell
Oxfordshire OX11 0QJ
Tel: 01235 432450
Fax: 01235 519422
Email: NRE-enquiries@aeat.co.uk

Industry Bodies

British Biogen
Energy Crops Network
7th Floor
63–66 Hatton Garden
London EC1N 8LE
Tel: 020 7831 7222
Fax: 020 7831 7223
Email:
info@britishbiogen.co.uk

National Farmers Union
Alternative Crops Adviser
Agriculture House
164 Shaftesbury Avenue
London WC2H 8HL
Tel: 020 7331 7275
Fax: 020 7331 7410
Email:
nick.starkey@nfu.org.uk

Forestry and Timber Association
5 Dublin Street Lane South
Edinburgh
EH1 3PX
Tel: 0131 538 7111
Fax: 0131 538 7222
Email: info@forestryandtimber.org

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Enquires relating to this publication should be addressed to:

Ian Tubby
Silviculture and Seed Research Branch
Forest Research
Alice Holt Lodge
Wrecclesham
Farnham
Surrey GU10 4LH

Tel: 01420 22255
Fax: 01420 520558
Email: ian.tubby@forestry.gsi.gov.uk

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