DTI New and Renewable Energy Programme

SHORT ROTATION COPPICE FOR ENERGY PRODUCTION HYDROLOGICAL GUIDELINES

B/CR/00783/GUIDELINES/SRC
URN 03/883

Contractor
Centre for Ecology and Hydrology

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The work described in this report was carried out under contract as part of the DTI New and Renewable Energy Programme, which is managed by Future Energy Solutions. The views and judgements expressed in this report are those of the contractor and do not necessarily reflect those of the DTI or Future Energy Solutions.

First Published 2003
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Introduction

These Guidelines are for growers, land and water resource managers, environmental organisations and any parties, interested in Short Rotation Coppice (SRC). It is hoped that the Guidelines will enable you to decide if a location is suitable for planting SRC when the likely crop productivity is weighed against possible adverse hydrological impacts. To assist in this task we consider various issues including:

- the water use of SRC compared to other crops;
- what factors govern the water use;
- what the water requirements are for a productive crop;
- and what impacts are likely on the availability and quality of the water.

When reading these Guidelines you should remember that although we know a lot about the processes controlling the water use and growth of SRC through recent research, there are still gaps in our knowledge. These gaps coupled with the variability of natural systems, and climate change, inevitably give rise to uncertainties in predictions which in some situations will be large.

Information that defines certain terms, or is of supplementary interest, is included in shaded boxes.

Basic considerations

- Because it uses more water than nearly all other vegetation in the UK (see the next section) sites must be carefully selected to ensure that the growth and yield of SRC do not suffer as a result of too little water.

- Water use and growth will vary across the country. (The sizes of the differences and the variation between varieties are being studied through a national network of field trials. The results from this study will provide valuable information on the most appropriate varieties to grow.)

- The low value of SRC makes it uneconomical to irrigate and it is therefore essential that it is planted in locations where there is adequate rainfall, or readily available soil water, or both.

- At the same time the presence of SRC should not so deplete the available water resource as to cause adverse hydrological impacts such as seriously reducing aquifer recharge and/or stream flow (see Figure 1), which may feed reservoirs, wetlands, water meadows or other fragile ecosystems.

- The effect of SRC plantation on water quality must also be considered. In general this will be beneficial but the possibility of increased NO_3 or other pollutants in surface runoff or ground water must be considered.

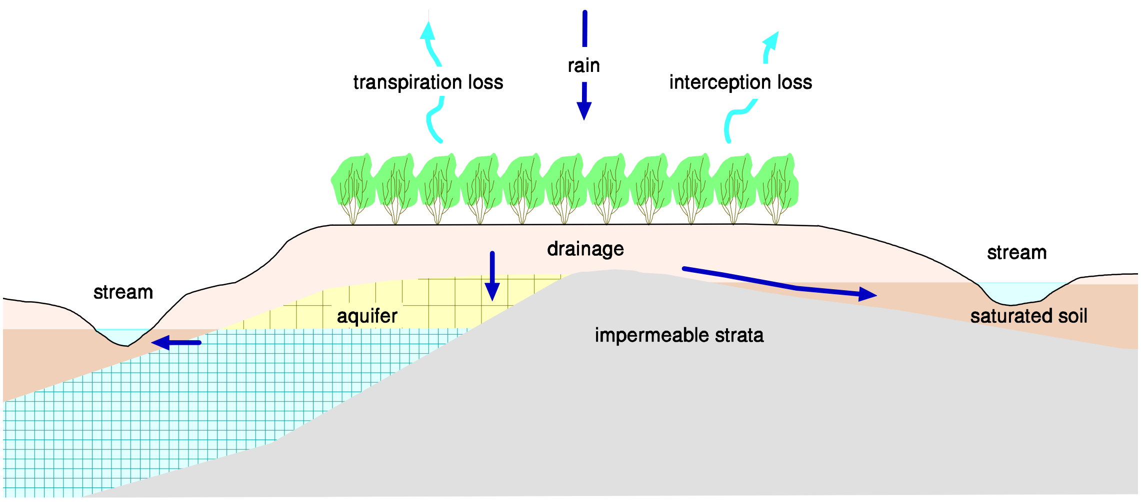

Figure 1 The main components of the water balance. Drainage beneath SRC will go to recharging aquifers or to stream flow, which in turn may feed reservoirs or wetlands etc.

How much water does SRC need?

Over the last few years, research, in the UK and on the continent, has shown that willow and poplar SRC use large quantities of water. The most detailed work in the UK has been on poplar, but differences in water use between poplar and willow SRC are likely to be small. Specifically:

> ***Water use***
>
> Water is used by vegetation through two processes, transpiration and interception. In transpiration, water is removed from the soil through the plants' roots and evaporated into the atmosphere from stomatal pores in the leaves. In interception, rainfall or snow, intercepted by plants is evaporated directly back into the atmosphere without ever reaching the soil.

- For the UK, the water use from mature SRC during the summer months exceeds that from all other vegetation and on an annual basis is second only to coniferous forest.
- The high water use is the result of, (i) high transpiration rates that can be sustained even during dry periods on deep soils, and (ii), large interception losses resulting from large leaf areas.
- Transpiration is the largest component of the SRC water use and this will be affected by the availability of water for the plants during the growing season; affected by the rainfall and soil.

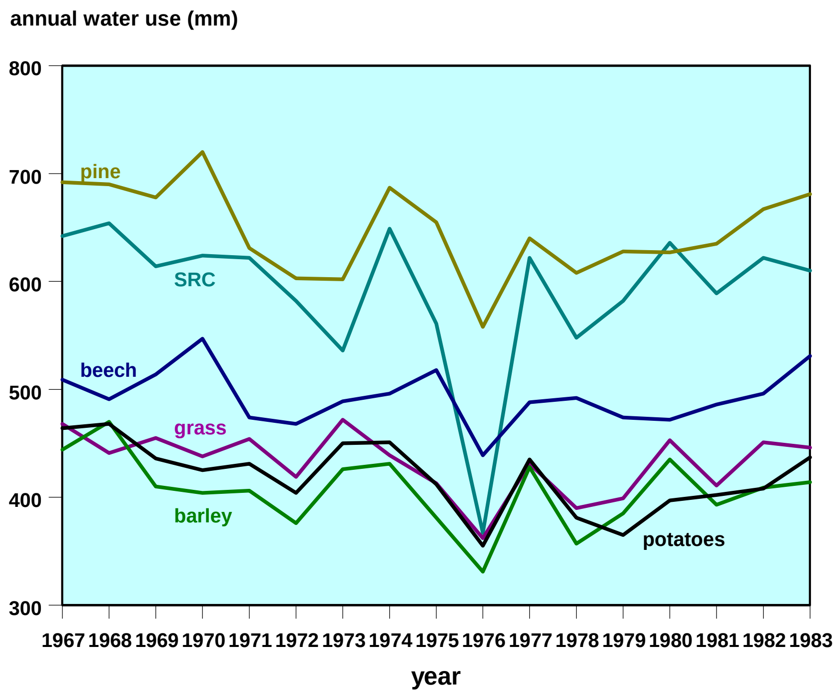

Figure 2 The annual water use of different crops

- As part of a DTI-funded study it was estimated that for a clay soil site with annual rainfall of about 700 mm, poplar SRC will use about 600 mm water compared to about 400 mm for barley or wheat (including evaporation from the soil), about 475 mm for broad-leaved trees, and about 650 mm for pine forest (see Figure 2).

  – The water use of willow SRC in the UK is unlikely to be significantly different. The water use of energy grasses such as *Miscanthus* is likely to be somewhere between SRC and grass but nearer to SRC.

  – The corresponding average reduction in annual drainage (in mm) caused by replacing various crops by SRC on two different soils, clay and chalk (representing a soil with freely available water) are:

	grass	**barley**	**potatoes**	**sugar beet**	**bare soil**
clay	153	179	166	87	216
chalk	150	189	179	113	246

- After each harvest the stems have to grow again and the leaf area increase, so that despite rapid growth, the water use in the first year after harvest is likely to be less than in the following two years (in a three-year cycle). Thus staggering the harvesting of different blocks between years provides a means of reducing peak water use.

- On the basis of a simple Swedish model relating biomass produced by willow for each unit of water used, we can estimate the average rainfall needed *over the growing season* to meet fully the water needs of SRC, well supplied with nutrients, to produce a yield of about 12 oven-dry tonnes ha^{-1}. This average *seasonal* precipitation is about 550 mm and corresponds to an *annual* UK average of about 1200 mm.

  – In areas with lower rainfall if SRC is planted on shallow soils and there is no alternative water supply, then the yield will be reduced. If planted on deeper soils then the SRC is likely to produce large deficits of soil water.

– If summer rainfall is less than about 300 mm (*annual* average about 700 mm) then yields are most unlikely to reach 12 oven-dry tonnes ha^{-1} with currently available varieties, unless there are additional water sources.

Transpiration and interception losses

Annual transpiration from SRC with three-year old shoots is higher than for other vegetation, with typical transpiration losses for poplar and willow plantations of around 500 mm a year compared with typically 375 mm a year for broadleaf forests. The reasons for this are:

1) The transfer of water vapour through the stomatal pores of SRC species is more rapid than for many other species.

2) To sustain rapid growth, SRC plants develop: (i) extensive, and in suitable soils, deep, root systems, that make available large water reserves that can be used during dry periods, that are unavailable to shallower rooted crops; (ii), large leaf area to maximise the capture of sunlight for photosynthesis.

Interception losses from SRC plants are also large as a result of large leaf area. During the leafy period in the third year of growth interception losses are about 20% of the rainfall: much the same as for mature broadleaf forest in full leaf, in the UK. The equivalent rate for most food crops is lower, peaking at about 15% or less, largely related to their smaller stature and leaf area. From a very small amount of data available from one study, it appears that interception loss from SRC during the leafless period is about 12% of the rainfall. The perennial nature of the crop results in significantly greater annual interception loss than from annual crops.

Where to grow SRC in the UK?

Large-scale plantation of SRC could pose problems in eastern England where the effective precipitation is small (see Figure 3, where the effective precipitation has been calculated as the difference between the precipitation and evaporation from grassland), and where groundwater recharge is already low. Reduced aquifer recharge would thus be serious in areas where groundwater is the major source of water supply. Additionally, in this area pollutant concentrations in the drainage water could be high and seriously degrade water quality. However, by carefully selecting the sites and controlling the area to be planted, these potential problems can be overcome - high water use need not create a hydrological problem. Moreover, in many locations it will be possible to take advantage of the high water use and extensive rooting of SRC, e.g. to dry marshy fields, to reduce the start and depth of flooding by increasing soil water storage, to reduce erosion by stabilising the soil through root systems.

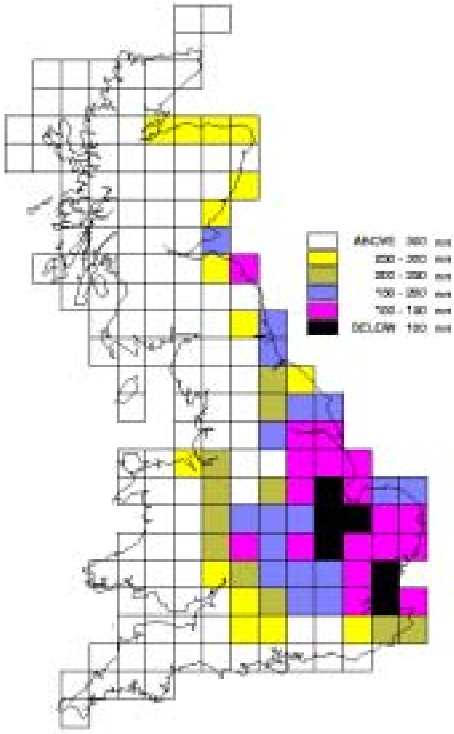

Figure 3 The effective precipitation across Great Britain. This map is based upon data from MORECS. Contact the Met. Office for more information.

The largest area of SRC plantations is likely to be in the west of the country where rainfall is greatest because:

- In wetter parts of the country economic yields from SRC will be possible at more locations than in the drier parts. In the west, growth is less likely to be limited through inadequate water. Provided there are sufficient sunshine hours, the plentiful rain should produce high yields.

- At the same time the high water consumption of SRC will not generally have serious consequences for water resources in the region. These areas also correspond to the areas of lower population density so that more land is available for planting, and human water consumption is lower.

- However, there may be situations where reduced surface flows could cause problems e.g. in Devon and Cornwall where 90% of the water supply is from surface waters, and where during the summer the population greatly increases through holiday visitors. Thus, significant areas of SRC should not be planted in reservoir catchments.

Specific site issues

When selecting a location for planting SRC you should take account of the soil, including any sub-soil, and any weathered rock or chalk below the soil layer that may all be able to supply water, remembering that:

- the water store will be larger for deep soils than shallow soils;
- for the same depth of soil more water is stored in clays than loams which in turn store more than sandy soils;
- as the soil becomes drier so the water becomes harder to extract, especially in clay soils;
- the depth of the soil is more important than the type as regards available water because of the efficient rooting of SRC.
- At sites where the summer rainfall is less than about 550 mm the plants will create soil water deficits over the summer:
  - On shallow soils the soil water store will be exhausted quickly, and in many years this will result in soil water stress with corresponding stomatal closure and restricted productivity. The quantity of water draining from the bottom of the soil profile in these circumstances will be similar to that beneath food crops.
  - At sites with deep soils, large reservoirs of available water will allow deeply rooted SRC to continue transpiring at high rates throughout the summer. When summer rainfall is small a large soil water deficit will develop so that, at these

sites, there will be less water draining from the bottom of the soil profile, available for aquifer recharge or stream flow, until the soil water is replenished.

- Willow is able to cope with water logging over prolonged periods and would be suitable for planting in fields subject to rising or perched water tables or in areas prone to flooding. Poplar does not do well at water logged sites but is able to access water from a water table and do well when grown over shallow water tables (1 – 2 m deep) in soils with high capillarity.

- The highest risk of water shortage will be during the summer on small, heavily planted catchments, because of their smaller storage potential. Springs and ephemeral streams may dry up sooner and for longer than before SRC was planted.

- The high water use of SRC may be used to advantage to reduce peak flows and delay the onset of local flooding: using them to dry the soil profile on deep soils with large potential water storage would result in the soil accepting more winter rainfall before reaching saturation.

- There is some evidence from a DTI-funded study that willow roots will enter and potentially clog field drains. This study revealed some differences in the rooting characteristics of different varieties but found no evidence of poplar roots (see Figure 4) entering drains.

Figure 4 A root system from poplar SRC dug up at the end of the second three-year cutting cycle (photo. Ian Tubby, Forest Research)

- SRC should not be planted close to, nor surround, archaeological sites. There is large uncertainty as to the appropriate separation, but it would seem prudent not to plant closer than 50 m to the remains from hydrological considerations. However, the requirement for heavy machinery to be able to turn and approach the plantation may set a longer separation distance.

- It is also possible that economic considerations will also come into play and the potential disbenefit of high water use may be overridden in favour of proximity to end users.

Reducing water consumption

- The most effective step to reduce water consumption, without affecting productivity, will be to plant new varieties with higher water use efficiency when they become available.

- Evaporation losses are likely to be less if plantations are formed as a few large blocks rather than many small blocks because of edge effects:

  - plants at the edge of a block receive more radiation and are subject to less competition from their neighbours, consequently they tend to grow larger and have a bigger leaf area and thus evaporate more water than plants in the middle;

  - the degree of enhancement should be related to the prevailing wind direction: evaporation from blocks planted perpendicular to the prevailing wind should be greater than if planted parallel.

  - At present we do not know the size of this edge effect, but studies to evaluate it are in progress as part of a DTI-funded project.

- It is also recommended, that the practice of staggering harvest times within a catchment be adopted so that the variation in the gross annual water use of an area planted with SRC is reduced.

How much to grow?

When deciding how much to plant you should consider competing water uses; whether they be water abstraction for agricultural, industrial or domestic supply, or natural ecosystems. The Environment Agency is now implementing the new CAMS (Catchment Abstraction Management Strategy) process and will be able to provide information on current abstraction licences and requirements for water meadows etc

Non-riparian plantations

The important factor in deciding how much SRC to plant is the scale of the plantation relative to the area of land under consideration. For example in an area with annual precipitation of 600 mm:

- If 2500 ha were planted within a 40 km radius of a power station, the reduction in the effective precipitation across the whole area would be negligible at about 0.5%.

- But, if the 2500 ha were planted across a small catchment then the effect on the local hydrology would be serious, effectively eliminating the whole of the effective rainfall and causing reduced stream flow and aquifer recharge in that catchment.

Figure 5 shows the possible percentage reduction in effective precipitation over a whole catchment, produced by planting different fractions of the catchment with SRC, for different annual rainfall. In producing these percentages it was assumed that poplar SRC was planted on a clay soil in place of an average food crop and that its transpiration was appropriately restricted as a result of water stress in dry areas. The greatest reduction in effective rainfall is in the driest areas of the country but the maximum reduction does not occur at the minimum rainfall since for these locations the transpiration from the SRC is severely reduced by the water stress.

In very dry regions where the annual precipitation is below about 600 mm, SRC will use all of the effective precipitation and so only a small proportion of a catchment should be planted. In these areas the impact in reducing catchment effective precipitation will be proportional to the area planted.

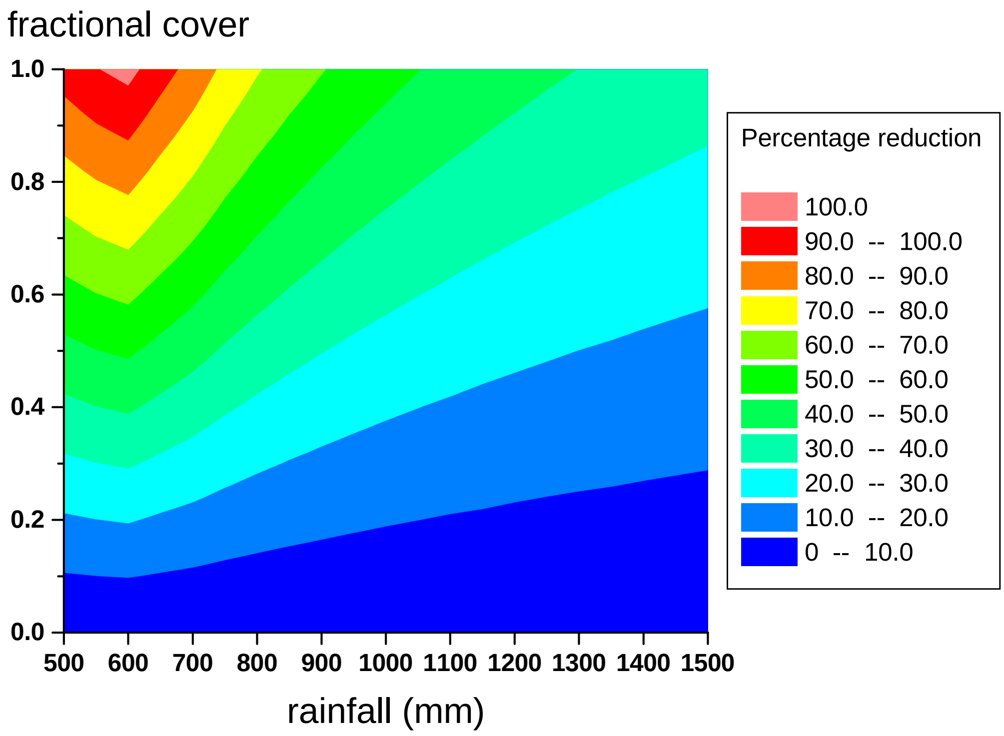

Figure 5 The percentage reduction in effective rainfall over a catchment as a function of rainfall

Riparian plantations

Because of the readily-available water in riparian soils, very high rates of transpiration and growth can be expected. The amount of water abstracted from the water course by the trees will depend upon various factors including the length and width of the plantation, the type of soil, and the rainfall. On the basis of some crude assumptions it is possible to estimate the likely maximum additional volume of water abstracted daily from a water course for different dimensions of plantation, for SRC in a shallow soil on sand and gravel. Figure 6 shows the additional abstraction expected compared with grass, expressed as an average rate, for a riparian strip of SRC on one side of a stream.

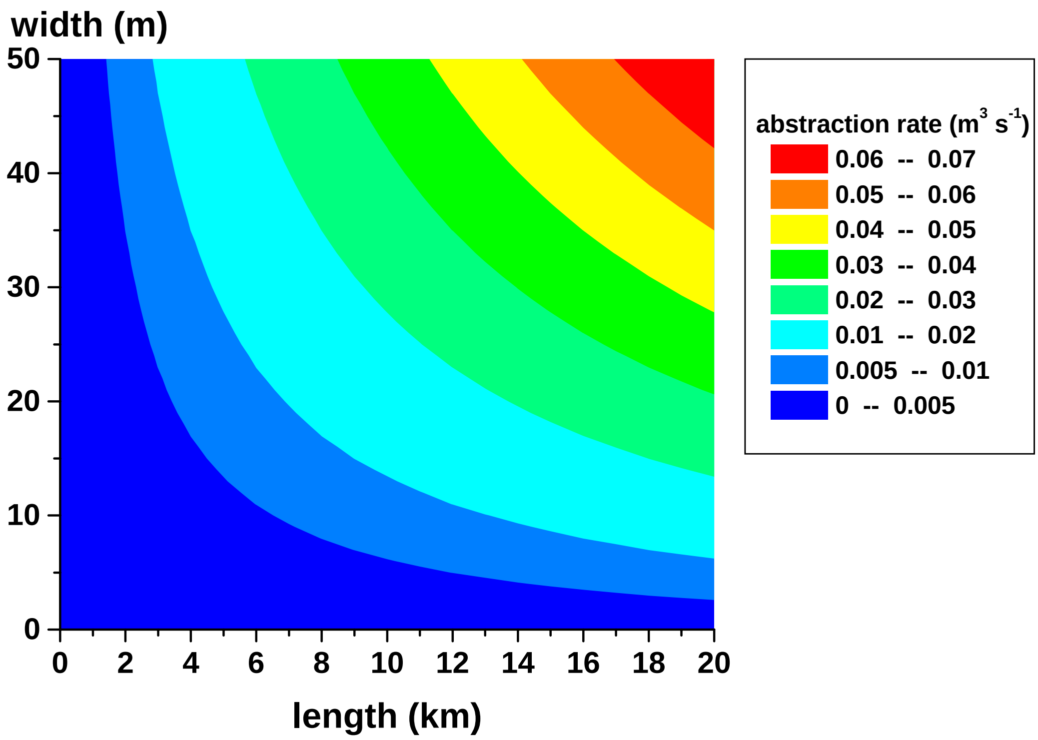

Figure 6 Maximum additional abstraction rates for riparian SRC planted on one bank

- Compared with many streams and rivers, these abstraction rates are low and it would require large plantations (several kilometres in length) to produce detectable reductions in water level.

- However, the additional abstraction rates are typical of mean flows recorded in some small gauged streams and for these, riparian plantation could seriously reduce the levels or even dry them up completely. Planting just 1 km of SRC 50 m wide could be serious for a headwater stream. This would obviously have implications for any fish or amenity ponds fed by them.

- Upstream from wetlands riparian SRC would reduce inflow, and possibly threaten the sustainability of the wetland during long dry periods.

Water quality issues

The impact of energy crops on surface and groundwater quality will depend on many factors including the previous land-use, soil type, hydrological regime and the past and future use of fertilizers and pesticides. The main points to remember regarding water quality are:

- On good quality agricultural land, including set-aside, ***the impact of energy crops on water quality is likely to be beneficial*** because far less pesticides or fertilisers will be used than with traditional farming.

- After the establishment year, the use of herbicides for SRC should drop rapidly and herbicide leaching should be minimal and is unlikely to be detectable in most surface and groundwater sources. Broad spectrum insecticides, used against beetles on willow, degrade rapidly in the soil and their impacts on water quality are likely to be minimal.

- The most contentious practice as far as water quality is concerned is probably nitrate leaching from N fertilisers and sewage sludge particularly where the SRC is situated in NVZs (Nitrate Vulnerable Zones). The amount of nitrate leaching beneath SRC is likely to be the most important water quality aspect to cause concern especially in the light of new evidence that yields are improved with judicious use of N.

Nitrate Vulnerable Zones

The EC Nitrates Directive has led to the designation of Nitrate Vulnerable Zones (NVZs) in catchments used for public water supply. A recent judgement by the European court of Justice (December 2000) ruled that the UK has not implemented the Directive fully and there may have to be increase in the area subject to NVZ regulations: the whole of England is one option being considered, or specific NVZs each with their own Action Programme, covering perhaps 80% of the land area of England, is another. In essence, the NVZ regulations demand that N fertilisers are not to be applied in excess of crop requirements and will mean yearly assessments of individual fields, taking account crop type and existing nutrient availability in the soil from previous applications of fertilisers, crop residues and organic manures. The aim is to balance supply with demand, so that there is little surplus nitrate left to contaminate water sources.

How much nitrate leaches in any location reflects a large number of site-specific factors and unfortunately there are few measurements available. However, what can be said with some confidence is:

- In the drier, south-eastern part of Britain the nitrate concentration in the drainage water is critically dependent on the effective rainfall. Effective rainfall is likely to be less than 150 mm a year and so even low rates of nitrate leaching could give nitrate concentrations close to or exceeding the 11.3 mg l^{-1} NO_3-N limit for drinking water (see Figure 7).

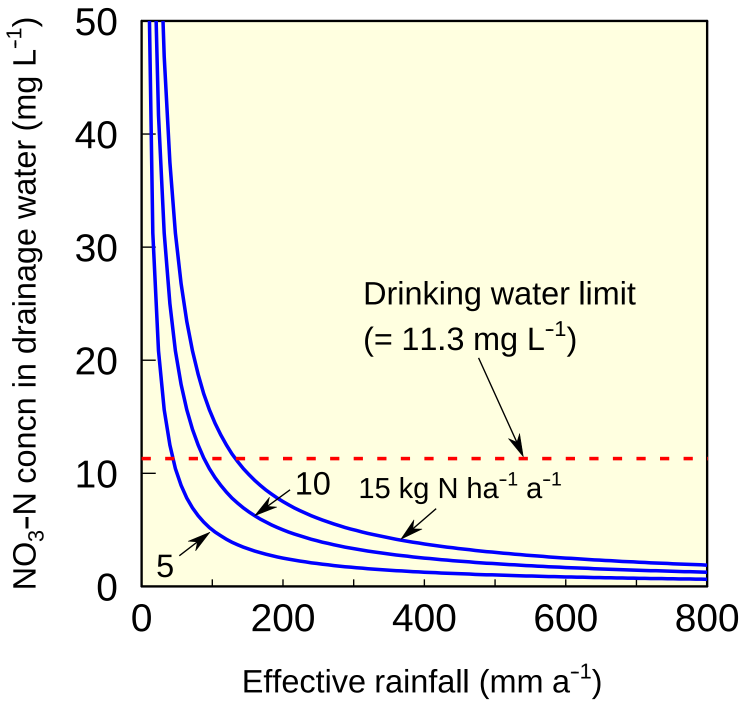

Figure 7 The change in the concentration of nitrate nitrogen in drainage water with effective rainfall

- Where there is a legacy of nitrate or mineralisable nitrogen from previous land use, a newly established SRC plantation does not appear to be able to reduce the nitrate leaching to low levels in the first few years

- Sewage sludge application rates using the current Codes of Practice give measurable increases in nitrate leaching but the effect from single applications appears to be short-lived and the amount of nitrate leaching could well be less than from land under intensive agriculture. The maximum annual amount of water applied during the application of sludge is likely to be of the order to 10-20 mm. After 31 December 2005 it will only be permitted to apply *treated* sludge to SRC

- Recent evidence does seem to point to some benefit from the use of fertilisers (especially N fertilisers), however, only modest rates should be applied. Evidence from Sweden and Denmark as well as from the UK demonstrates that applications of 70-100 kg N/ha/yr will not result in excessive nitrate leaching once the crop is established, i.e. after the first year. There are large uncertainties in this and a 'dose-response' relationship needs to be established at a few key sites across the UK, with continuous monitoring for at least two years after the last sludge application.

- SRC and other energy crops provide a good outlet for the disposal of sewage sludge. At present, application limits are governed by DEFRA regulations which limit total nitrogen from organic manures to 250 kg N/ha/yr.

- Subject to this limit, higher-than-necessary (for plant growth) N loadings can be used on SRC so that it "treats" various problematic waters such as municipal wastewaters, landfill leachate and high nitrate agricultural drainage water.

- SRC could be used as buffer strips planted alongside rivers to protect against nutrient and sediment runoff from adjacent farmland. Work in the US has shown that a mixture of tree and grass species considered for energy crops, can be effective as buffer strips.

Bibliography

This is not an exhaustive list of publications. The first two references are reports produced for the DTI and DEFRA respectively, and are the most detailed and relevant documents in the bibliography, containing many references to scientific papers and reports that are not appropriate to list here. The model used to calculate the water use of SRC and other crops is described in the first report.

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Useful contacts

Information about environmental legislation and the Catchment Abstraction Management Strategy process can be obtained from:

- Environment Agency
  Rio House
  Waterside Drive
  Aztec West
  Almondsbury
  Bristol
  BS32 4UD
  http://www.environment-agency.gov.uk/

Information about DEFRA-funded research projects can be obtained at:

http://www.defra.gov.uk/

Information about DTI-funded research projects can be obtained at:

http://www.dti.gov.uk/renewable/renew.htm

Glossary

aquifer	layers of rock or unconsolidated material able to store and transmit significant volumes of water
catchment	the area feeding a river or reservoir
drainage	the water that percolates through the soil beneath a crop and goes to replenishing the water stored in an aquifer, which also ultimately feeds surface waters, or, if the substrata is impermeable, flowing laterally through the soil until reaching surface waters
ecosystem	a complex of plant and animal communities and the associated environment
edge effect	enhanced evaporation at the edge of a block of vegetation
interception	the process in which rainfall or snow, is intercepted by plants and evaporated directly back into the atmosphere without ever reaching the soil.
leachate	a solution of materials draining from the soil
riparian	the land immediately bordering a water course
stomata	pores in the leaves of plants through which water vapour and carbon dioxide pass
transpiration	the process through which water is removed from the soil through the plants' roots and evaporated into the atmosphere from stomata in the leaves.
soil water deficit	the difference between the amount of water stored in the soil and the amount that the soil holds when drainage has ceased following saturation