QUANTIFYING BIOMASS PRODUCTION IN CROPS GROWN FOR ENERGY

ETSU B/CR/00387/REP

Contractor
ADAS

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GLOSSARY OF TERMS

a i	-	active ingredient.
biofuels	-	sources of energy derived from non-fossilised plant matter.
biomass	-	the weight of all the plant material forming a given plant population.
biosynthesis	-	the synthesis or organic compounds (see photosynthesis).
brackling	-	buckling of the straw at a point well above ground level. It occurs particularly in barley and oats, when the crop has become over ripe.
chlorotic	-	discoloured, greenish yellow.
clonal	-	belonging to a clone.
clone	-	the descendents produced vegetatively from a single plant.
cutterbar	-	cutting blade on a combine harvester.
denitrification	-	breakdown of nitrates and nitrites under anaerobic conditions.
DM	-	Dry matter (dry biomass).
EC	-	European Community, European Commission.
ECU	-	European currency unit.
edaphic	-	of the soil.
EU	-	European Union.
genotype	-	genetic constitution of an organism defined by a particular set of alleles present in each cell of an organism.
germplasm	-	a particular sort of protoplasm that is transmitted substantially unchanged from generation to generation via the germ cells, giving rise in each individual to the body of cells (soma) but itself remaining distinct and unaffected by the environment of the individual.
graminaceous	-	grass like, of the family *Gramineae*.
heterozygous	-	having unlike alleles at one or more corresponding loci (opposite to homozygous).
internodal	-	situated in the internode.

internode	-	part of a plant stem between two successive nodes.
kg ha $^{-1}$	-	kilogrammes per hectare of land.
LAI	-	leaf area index. The unit area of leaf per unit area of land.
leaf area index	-	see LAI
lignified	-	possessing lignin.
lignin	-	complex aromatic compound which is deposited in cell walls of woody plants and trees giving them strong and rigid stems.
lignocellulose	-	complex compound of phenolic and cellulosic substances present in woody material.
lodging	-	when the crop goes down, from the base of the plant to an angle greater than 45^{o} to the vertical.
meristematic	-	of the meristem.
mesophyll	-	internal tissue of leaf blade differentiated into palisade and spongy mespohyll.
micropropagated	-	see micropropagation.
micropropagation	-	vegetative propagation of plants from small groups of cells taken under aspetic conditions from the apical growing point of the mother plant.
MJ	-	mega joules or 1 000 000 joules.
NFFO	-	non-fossil fuel obligation.
odt	-	oven dry tonne
phenology	-	measured or observed differences in appearances of a plant.
photosynthate	-	organic compounds of photosynthesis.
photosynthesis	-	synthesis of compounds in green plants from water and carbon dioxide using energy absorbed by chlorophyll from sunlight.
plumose	-	feathery, consisting of long hairs which are themselves hairy.
propagule	-	any part of a plant capable of growing into a new organism; e.g. seed, spore, cutting.

raceme	-	kind of inflorescence.
rachis	-	main axis of an inflorescence.
rhizomatous	-	bearing rhizomes.
rhizome	-	underground stem, bearing buds in axils of reduced scale- like leaves; serving as a means of perennation and vegetative propagation.
senescing	-	process of ageing, decay and death of plant tissue.
soil moisture deficit (SMD)	-	amount of water (mm) required to return the soil to field capacity.
spikelet	-	grass inflorescence generally consisting of two glumes and one or more flowers each borne between a lemma and palea.
stomata	-	pore in the epidermis of plants, present in large numbers, particularly in leaves, through which gaseous exchange takes place.
sward	-	carpet of grasses, clover and other grassland species covering the ground in a pasture.
taxonomy	-	study of the classification of organisms according to their resemblances and differences.
t	-	tonnes or 1000 kg of mass.
t ha^{-1}	-	tonnes per hectare of land.
tillering	-	formation and production of side shoots from the base of a plant near to the ground.
translocation	-	transport of materials within the plant through the vascular system.
transpiration	-	loss of water vapour by land plants; occurs mainly from leaves, chiefly through stomata.
vascular	-	containing or concerning vessels which conduct fluid; in plants water, mineral salts and photosynthates are conducted in vascuular tissue consisting esssentially of xylem and phloem.
vegetatively	-	growth of plants by production of leaves, stem and roots prior to the formation of reproductive organs.

1. INTRODUCTION

1.1 Project Background

One estimate[1] suggests that continued CAP reform may lead to as much as 2 million hectares of land set aside from arable production by the year 2020 in the UK alone, with 20 million hectares in the EU in total. Set-aside currently occupies more than 500,000 hectares in the UK. Set-aside land is providing more opportunities for non-food crops, for example fuel crops, which provide biomass for energy.

Whilst any crop species will produce biomass which can be burnt to produce energy, arable crops were not developed with this in mind but rather a specific harvestable commodity, e.g. grain, and therefore the total harvestable commodity is seldom maximized. The characteristics of an ideal fuel crop have been identified[2] as:

- Dry harvested material for efficient combustion.
- Perennial growth to minimise establishment costs and lengthen the growing season.
- Good disease resistance.
- Efficient conversion of solar radiation to biomass energy.
- Efficient use of nitrogen fertiliser (where required) and water.
- Yield close to the theoretical maximum.

Miscanthus, a genus of Oriental and African C4 perennial grasses, has been identified as possessing the above characteristics. There may be other species, which, if not yielding quite as much biomass, have other characteristics of merit. This has led to the need to identify inherently productive species which are adapted to the UK, and to validate the productivity of species which have already been 'discovered'.

With this in mind, this project began in 1993 with the following specific objectives:

1. To quantify the yield potential of *Miscanthus x giganteus* Greef et Deu[3] at four sites in southern England.

2. To evaluate the relationship between climate and yield potential throughout Europe by participating in the EC Miscanthus Productivity Network and following a common experimental protocol.

3. To assess the environmental impact of growing and harvesting biomass crops by measuring crop growth, habitat value and biodiversity and identify adverse effects on the rural community.

These objectives have been approached in a suite of experiments that can be broken down into three components; unreplicated small plot assessments of novel species, simple replicated trials with the more promising species and complex multi-site experiments involving Miscanthus. Species which have shown promise in the first assessment year have been

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[1] Grassi, G. & Bridgewater, A. (1991). The European Community energy from biomass research and development programme. *Journal of the Institute of Solar Engergy* **10**, 127-136.

[2] Anon. (1991). Non-food uses of agricultural products. *House of Lords Paper 26, Select Committee on the European Communities, 7th Report, Session 1990-91,* 104-108. London: HMSO. 219pp

[3] Classification based upon the following reference, which updates the original classification of *Miscanthus sinensis* 'Giganteus'. Greef, J M & Deuter M. (1993) Syntaxonomy of *Miscanthus x giganteus* Greef et Deu. *Angewandte Botanik*, **67**, 97-90.

included in replicated trials in subsequent seasons. Thus a system of continual appraisal has ensured that only the most suitable crops are carried forward to the next scale of assessment.

This report has the following objectives:

- To review progress of the European Miscanthus Productivity Network.
- To summarise experiments which have been undertaken during the period 1993-95.
- To present fully analysed data from these experiments.
- To discuss the applicability of the different test species as biomass crops.
- To propose subsequent direction/objectives of research.

1.2 Experimental site details

The experimental sites were chosen to represent a cross section of soil types and fertilities available to growers in southern England:

ADAS Arthur Rickwood

A Research Centre of 75.4 ha of very fertile Grade I land located in the Cambridgeshire Fens at Mepal, near Ely. Soils are peaty loams over fen clay or gravel and are free-draining. Land is approximately 3 m below sea level, the climate is mild, typified by high summer radiation levels and high spring temperatures. The mean annual rainfall, 529 mm is low. Soils have a high weed burden, particularly of broad-leaved weeds and annual meadow grass.

ADAS Rosemaund

A Research Centre of 176 ha of Grade I undulating land 8 miles north east of Hereford. Soil type is silty clay loam mainly of the Bromeyard series , is naturally fertile and capable of growing very good crops if carefully managed. The climate is mild with an average rainfall of 660 mm.

IACR Rothamsted

The Rothamsted Farm has 330 ha of mainly arable land, although some is laid to grass. The farm is 96-134 m above sea level. Once again the climate is mild and the site receives an average 695 mm of rainfall each year. All trials were conducted in the same field which is grade II/III, loam over clay with flints ('typical' UK arable land). There are many common arable weeds present on the site. Those of greatest abundance are *Atriplex patula, Polygonum persicaria, Stellaria media, Senecio vulgaris, Chenopodium alba, Rumex* spp. and *Poa* spp. The field was previously cropped with winter beans (1992) and winter barley (1991).

Rosewarne

The CSMA trials have been established at Rosewarne. This site was formerly the MAFF Rosewarne EHF but is now owned jointly by Cornwall County Council, West Cornwall LEADER Project and the Duchy College of Agriculture.

The soil at Rosewarne is acid brown earth, Grade III agricultural land. The land is exposed with a north facing slope and is slightly protected by a shelter belt of trees to the west. The underlying rock is metalliferous slate ('killas') which gives rise to a very stony soil with elevated heavy metal contents (copper and arsenic) (Table 1.1). The farm has been in intensive broccoli and bulb production for many years and has a poor soil structure with little organic matter. Prior to planting in Spring 1993 the field was ploughed, cultivated and sprayed with the translocated herbicide glyphosate.

Table 1.1. Heavy metal concentrations ($\mu g\ g^{-1}$) and pH of Rosewarne soil

element	As	Cu	Zn	Ni	Pb	Cd	pH
concentration	395	307	368	46	219	nd	5

1.3 Climatological details

Summaries for the period 1993-1995 are presented in Figures 1.1 - 1.4. The four sites were thought to be climatically amenable to C4 crop species growth - relatively high radiation inputs and high spring temperatures. There were very minor differences in annual radiation receipts to the four sites over the experimental period, ranging from 3400 MJ m^{-2} yr^{-1} to 3800 MJ m^{-2} yr^{-1}. Precipitation levels were generally greater at Rosewarne, and winter maximum and minimum temperatures and summer minimum temperatures were also significantly higher at this site although summer maximum temperatures were lower.

Climatic data
Generally, the mean monthly maximum and minimum temperatures at Rickwood were slightly higher that those experienced at Rosemaund or Rothamsted. Temperature and rainfall patterns were generally similar. The maximum mean monthly temperature at Rickwood in 1995 was always greater than the site mean; during July and August, it was about 5 °C above the site mean. The start of the growing season at both Rothamsted and Rickwood was typified by late, severe frosts. The 1995 summer was one of the driest on record. At the peak of the drought Rothamsted had a 150 soil moisture deficit (i.e. below volumetric field capacity for this soil). At Rickwood five successive summer months had rainfall below the site mean.

The first shoots emerged on 30 March at Rickwood. These shoots appeared to be chlorotic, and were scorched by an air frost on 19 April which destroyed all the shoots. The plants started to produce new shoots almost immediately after the frost. The plants were again affected by an air frost on 13 and 14 May, which destroyed all the new leaves and stems. The plants took two weeks to recover fully from this late frost. From this point onwards, canopy development and stem growth were rapid. The site received no irrigation during the dry hot summer, which may have caused the plants stress and, thus, were not able to reach their maximum growth rate.

Figure 1.1 Cumulative global radiation receipts (GJ m^{-2}) for 1993 and 1994 at the four experimental sites

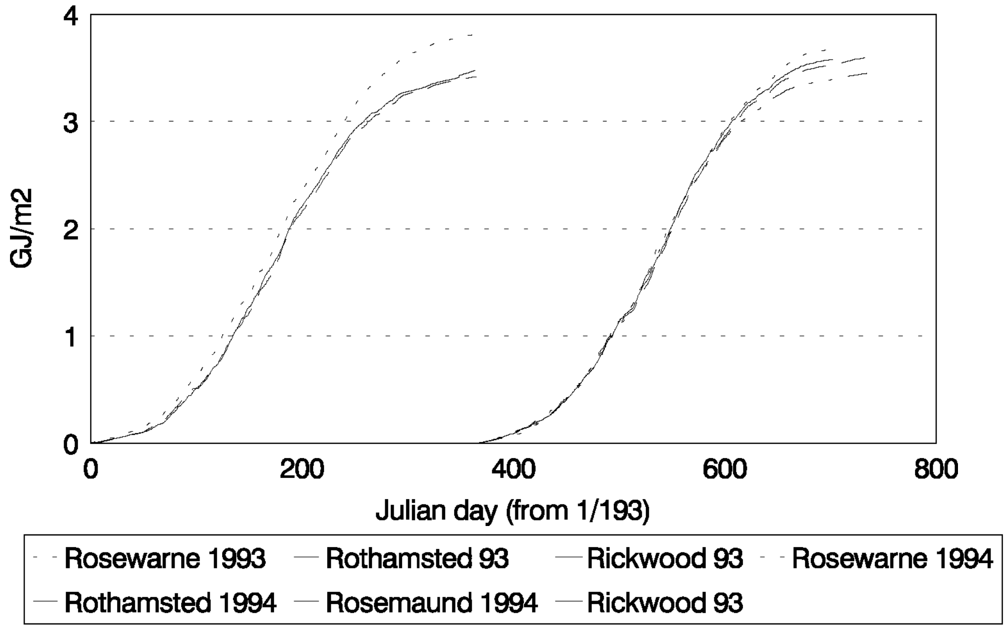


Figure 1.2 Monthly rainfall at the four experimental sites for 1993 & 1994

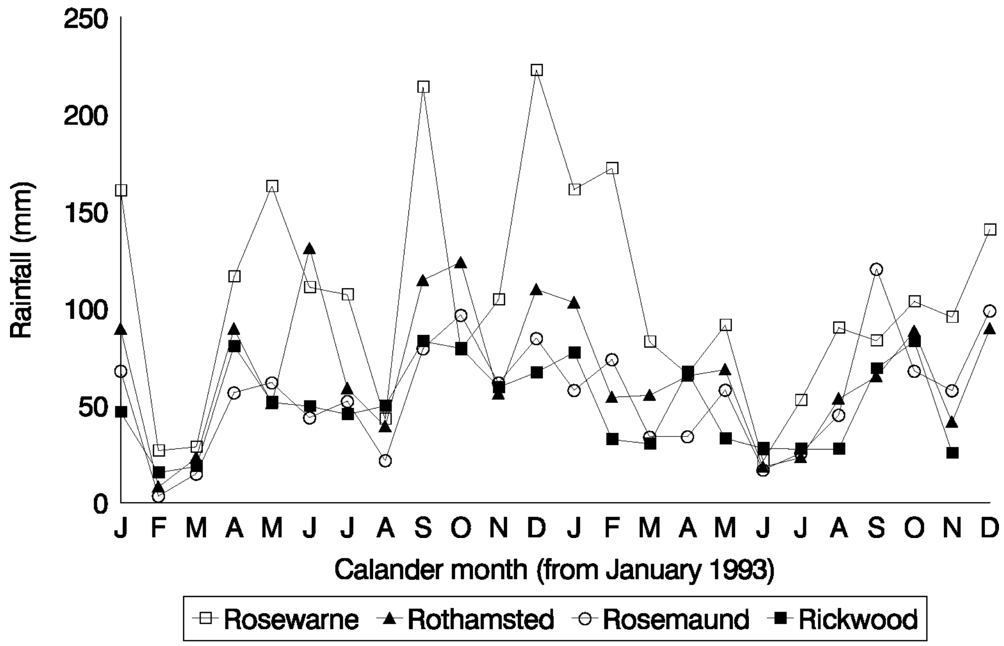


Figure 1.3 Mean monthly maximum temperatures (°C) at the four experimental sites, for 1993 and 1994.

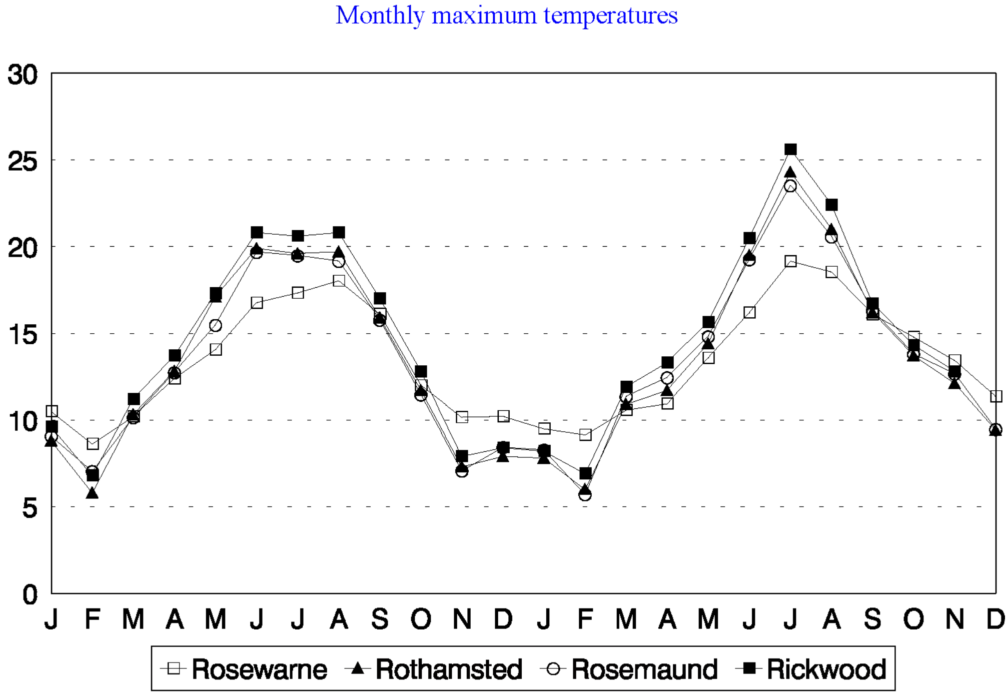
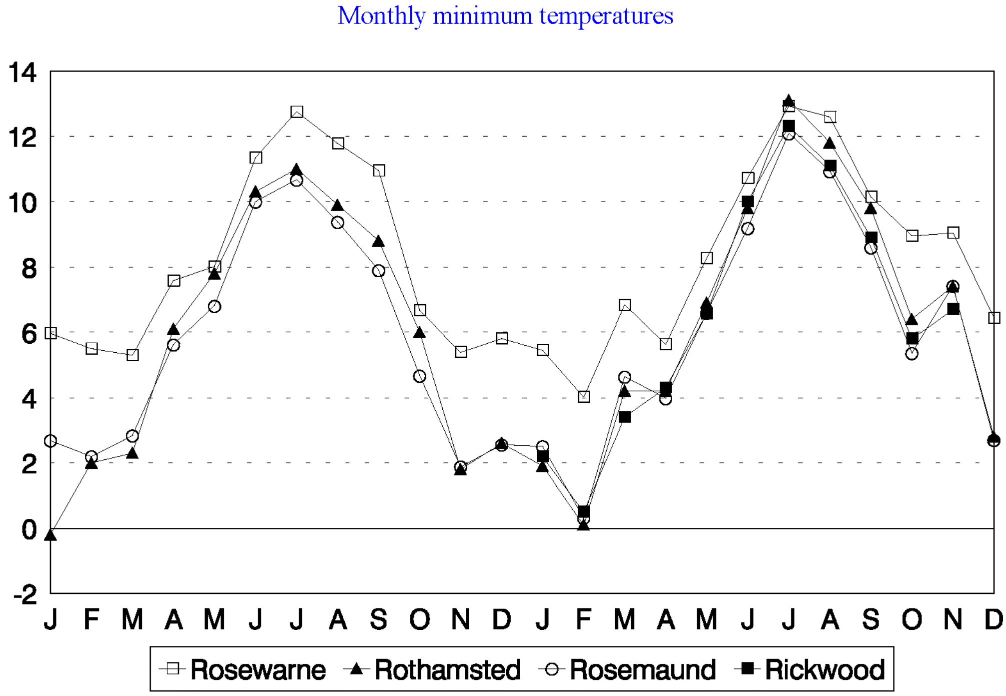


Figure 1.4 Mean monthly minimum temperatures (°C) at the four experimental sites, for 1993 and 1994.



2 OVERVIEW OF THE EUROPEAN MISCANTHUS NETWORK

2.1 Original Network - JOULE

The Miscanthus Productivity Network was established under the JOULE Programme of the European Community in 1989. The minimum experiment, which started in 1990, required a field of 34 m x 60 m for replicated trial with a minimum treatment involving two rates of fertiliser application (0,240 kg ha^{-1}) and a common source of *Miscanthus*. Eighteen locations throughout Europe received *M. x giganteus*' originating from the same source in Denmark (Bioflazen, Denmark, Aps). Experimental plots (10 m x 10 m) were established by spacing rhizome species and plantlets alternately at a distance of 50 cm.

The *Miscanthus* rhizomes failed to produce significant numbers of plants at most locations but in Monte de Caparica, Portugal and Brunschweig, Germany there were 75% and 72% success rates, respectively. The reason for the failure of the rhizomes was unclear; planting in June may be too late in the year for them to be viable. The survival rates of the plantlets were much higher, ranging from 88 to 100% at the end of the establishment year.

Dry matter yields of *Miscanthus* on a ground area basis at the end of the establishment growing season were very low. Stem or tiller production of *Miscanthus* was slow in the establishment year. At the end of the growing season the average number of tillers per plant varied from 2.5 at Cashel, Ireland to 15.8 at Braunschweig, Germany. Yields ranges from 0.75 t ha^{-1} at Kinsale, Ireland to 6.6 t ha^{-1} in Braunschweig, Germany. The yields showed a wide range of variability both intra- and inter-site due to a number of circumstances which included climatic conditions (temperatures and precipitation) at the time of and after planting, soil conditions and management during the early establishment of the plants. Most material was not irrigated on planting and many plants were subjected to heat and water stress at this time. The planting date also varied from 21 May in Brunschweig, Germany to 2 July in Madrid, Spain.

During the second year of growth, tiller production of all established plants increased markedly. Numbers per plant reached 28 at Lusignan, France and 30 at Koropi-Attikis, Greece. Production was less at the northerly sites but numbers reached 14 per plant at Cashel, Ireland. Here, the maximum plant height exceeded 200 cm, about twice the height reached in the establishment year. There were differences in the growth pattern of the rhizome- and micro-propagated plants. Rhizome propagated plants were taller but produced less tillers.

Harvestable yields after the second year of growth were considerably higher than first-year yields. There was, however, still a large amount of variability. The highest yields were recorded at Lusignan, France where 15 t ha^{-1} were harvested from a high N treatment and 12 t ha^{-1} from a zero N treatment. Only 2.1 t ha^{-1} were harvested at Wurzburg, Germany but yields there were probably depressed by low rainfall which only reached 65% of the average during that year. Selected yields from this and other trials within the EU are presented in Table 2.1.

Table 2.1 Dry Matter Yields of Miscanthus at Selected Sites Throughout Europe.

Site	Age of plants	DM yields
Essex, UK	2 yrs	20 t/ha
Catania, Italy	2 yrs	26 t/ha
SORGHAL, Belgium	3 yrs	21 t/ha
A. Biotec, Italy	3 yrs	23 t/ha
Lisbon, Portugal	4 yrs	22 t/ha
FAL, Germany	4 yrs	20 t/ha

These trials continue to be monitored at 4 sites.

2.2 Current Network - AIR

In 1992, a new European Miscanthus Network was established under the Agro-Industry Research (AIR) programme of Directorate General for Agriculture (DGVI). The objectives of this Network, which includes ADAS and Rothamsted, are detailed below:

1. To determine the sustainable yield and quality of Miscanthus as a low input agricultural crop at different locations in the EU, with particular emphasis on North Europe.

2. To assess the limitations which low temperatures and other stress factors place on the growth of Miscanthus under European climatic conditions.

Productivity Trials - Key results:
A standard protocol and monitoring of the field trial was specified by the Network. The experimental design provides plots of 10 m x 10 m and three replicates of 3 rates of yearly fertiliser application i.e. 0 kg N ha^{-1}, 60 kg N ha^{-1} and 120 kg N ha^{-1}. Each partner planted between 4,000 and 8,000 *Miscanthus x giganteus* micro-propagated plants in 1993. All the plants originated from the same source - Piccoplant, in Germany, and a total of 67,000 plants were established at 13 sites. At two week intervals the agronomic measurements defined in the protocol were taken (Table 2.2).

Table 2.2 Parameters Monitored in the Field Trials

Agronomic	Meteorological	At harvest
Plant death	Incident radiation	Fresh weight
Height	Incident PAR	Dry weight
Tiller number	Air temperature	Energy content
Leaf Area Index	Soil temperature	Ash content
Light Interception	Atmospheric humidity	Heavy metal content
	Precipitation	Mineral content

Crop Growth: The establishment rate of the plants was over 97%. Variations in Nitrogen treatments were found not to have a significant effect on plant heights, tiller numbers and yields. The average yield from the 1993/94 season was 2-4 t/ha.

Analysis of harvested material showed that, on average, 2/3 of the dry matter is found in stems and 1.3 in the leaves, and the ash content of the dry matter is higher in the leaves (~6% of DM) than the stems (~2.4% of DM).

The energy content of harvested material was measured at 18.2 MJ kg^{-1} which is similar to other biomass crops. (e.g. sugar beet = 18.5 MJ kg^{-1} & Poplar = 18 MJ kg^{-1}). Many partners noted a marked decrease in dry matter yields (up to 30% decrease) over winter, due mainly to loss of leaves. This loss in yields is compensated for by the decrease in moisture content (~ 25%) and increase in cellulose content (~25%) observed in later harvests.

Water stress experiments: The IAGCE, Catania, are conducting water stress experiments in order to quantify the influence of water availability on the growth of *Miscanthus*. Preliminary results show that differences in soil water content have a greater influence on above ground biomass yields than differences in Nitrogen treatments. An increase in soil water content from 25% to 100% of maximum resulted in an increase in DM yields from 15 ± 0.40 t ha^{-1} to 29 ± 2 t ha^{-1}. Whereas increasing Nitrogen fertiliser levels from 0 kg N ha^{-1} to 120 kg N ha^{-1} resulted in a yield increase from 19 t ha^{-1} ± 1.24 to 25 t ha^{-1} ± 3.0. However, both treatments interact positively with each other, as the greatest yield increase (of 143%) was found with the highest Nitrogen treatment. Leaf Area Index showed a similar behaviour of that of DM yields, with the highest values measured at the highest soil water and Nitrogen contents.

Nutrient Uptake: The results of these experiments will indicate the optimum fertiliser inputs that are required by *Miscanthus*. Nutrient uptake measurements of three year old plants showed that the highest uptakes were during May and June. Potassium showed the greatest uptake (highest uptake was 107 kg ha^{-1}), and Nitrogen had the next highest uptake (50 kg ha^{-1}), followed by Phosphorus (6 kg ha^{-1}) and Magnesium (3 kg ha^{-1}).

Winter Mortality: High winter mortality of young Miscanthus plants is proving to be a critical problem in the cultivation of Miscanthus in Germany and The Netherlands. For example, even though the trials at BFH, Hamburg had a 98% establishment rate, all the plants died over the 93/94 winter. Investigations are on-going into the exact nature of the stresses which affected Miscanthus plants during severe winters. Time of planting and genotype variety were also shown to have an effect on winter survival rate.

Harvesting and Storage Experiments: For harvesting, the best method identified to date, is a swath mower with a capacity of 2 ha/hr, a DM density of 130 kg/m^3 and a cost of 45 ECU ha-^{1}. The high pick-up losses (about 30%) incurred with this method, can be minimised by using an integrated mower/baler. In order to preserve the quality of the harvested material the maximum moisture content of the material for storage should be less than 25%. Once dry, high density bales can be stored successfully outdoors, as only the first 10 cm layer will absorb water, although storage under cover is preferable as this allows good air circulation. Cutting and chopping will produce lower density bales (70-100 kg m^{-3}) which may be preferable if the moisture content at harvest is too high (the low density of the material facilities drying during storage). In addition, briquetting and pulverisation are being investigated to facilitate the long-term storage of the crop. Briquettes have been manufactured from *Miscanthus* and developments are ongoing, to optimise their quality. Various pulverisation tests are being carried out in a Pahlmann PSKM-8-460 mill to produce milled Miscanthus for combustion experiments.

Genotype Screening: The techniques of isozyme analysis, restriction fragment length polymorphisms and field trials were used for taxonomic investigations and for selection of genotypes. A Miscanthus DNA bank has also been established. The taxonomy of the Miscanthus genus still needs further clarification as there is evidence of phenotypic plasticity in characteristics previously used to separate Miscanthus into different groups. This is being undertaken independently by a joint ADAS/Royal Botanic Gardens, Kew project which is funded by MAFF.

Low Temperature effects: Chlorophyll fluorescence and linear variable transducer systems are being used to examine low temperature effects and photo-inhibition. It has been established that leaf extension increases with a rise in shoot temperature, with the threshold temperature being 5-10°C and that the main site of low temperature damage occurs in photosystem II. All C4 plants are vulnerable to chilling dependant photo-inhibition. However, in contrast to Maize (the main C4 crop grown in Europe) Miscanthus can develop photosynthetically competent leaves at temperatures less than 15°C. Also, light saturated photosynthesis was unaffected by growth at 14°C in Miscanthus but was dramatically reduced in Maize.

Economic Analysis: The Network is collecting both scientific and economic data for economic analysis and modelling of the production costs of Miscanthus across Europe. Initial results show that the greatest cost factor is the cost of the plants. At a cost of 0.52 ECU/plants the break -even cost at the farm gate is 50 ECU/t @ a yield of 20 t DM/ha). However, with improved knowledge of agronomy, increased demand and grant payments will reduce the break-even costs. First estimates indicate that a reduction in plant costs to 0.33 ECU/plant or 0.20 ECU/plant would result in break-even costs of 37 ECU/t and 30 ECU/t respectively. Whilst establishment costs have been identified as a major factor limiting the economic feasibility of the crop, there is evidence from The Netherlands that planting costs could be reduced to *c.* 300 ECU (£250) per hectare Huiseman & Kortleve (1994) [1].

Energy Production: Various conversion routes for the manufacture of electricity from Miscanthus, are being examined including; combustion; co-generation (CHP); gasification and co-firing in a coal electricity plant. BTG, The Netherlands have completed a study on different conversion methods. The activities of the current Miscanthus Productivity Network finished in November 1995. The final report will present a detailed synopsis of the experiments described above. This report will be made available to ETSU in due course. Currently, the Network is submitting a concerted action proposal to FPIV for a 24 month project extension to allow continued agronomic measurements and further data modelling.

The synthesis report of the EU Miscanthus productivity will soon be published and will be made available to ETSU.

[1] Huisman W & Kortleve W J (1994). Mechanisation of crop establishment, harvest and post-harvest conservation of *Miscanthus sinensis* 'Giganteus'. *Industrial Crops & Products.*

3. THE ECONOMICS OF MISCANTHUS PRODUCTION

This report determines the feasibility of Miscanthus production in the UK by evaluating the economics of establishment and crop maintenance, against a likely background of product value. There are comparatively few published analyses of production economics; the only one (Rutherford & Heath, 1992) which is specific to Miscanthus is now out of date. Given the interest which is being generated by this crop genus, an appraisal of the economics is essential.

The consideration of crop gross margin (i.e. crop value minus all annual variable costs such as fertilisers, crop protection sprays, harvesting and establishment costs) is the most valid method for considering the economics of Miscanthus production. Throughout the work on which this summary is based we have worked on the basis of price per tonne of dry biomass required to break-even on variable costs. Consequently, all figures quoted in this work are independant of fixed farm costs and produce transportation costs. This approach was taken because fixed costs can differ tremendously depending on the nature and scale of the farming operation.

One particularly special consideration with a perennial crop is that all establishment costs can be deffered throughout the productive life of the crop in question. As we are currently uncertain about the potential lifetime of a Miscanthus crop, a default value of 15 years (conservative estimate) has been used throughout.

Knowledge gained during four years of Miscanthus agronomy research have been combined with patchy knowledge of the likely value of the final product. Before all economic factors are synthesised to produce gross margins and break-even costs, individual factors are considered separately.

The Variables

Site preparation

The provision of a good quality 'seed bed' is very important and will improve establishment (and consequently yield) by improving soil-plant contact and consequent moisture and nutrient supply. In the current model site preparation is set at a standard rate, one ploughing operation followed by one power harrow (mean Nix, 1995 values) conducted by specialist contractor. Clearly speed of operations (determined by soil type, tractor size and scale of cultivation) will effect the cost of cultivation, but as we will see later, this will not have a dramatic effect on long term economics.

Propagule costs and establishment costs

Current experiments establish Miscanthus at densities of 10,000 to 40,000 plants per hectare. The most appropriate density is not yet established, but on UK evidence might be nearer 10,000 plants per hectare. The most cost effective method of crop propagation would probably be through seeding. However, currently available ‘varieties’ do not set viable seed. Two alternatives, establishment from micro- or macro- propagation are currently used. At present, establishment of micro-propagated material (small plantlets produced via tissue culture) has proven to be very expensive. Small scale trials using hand-lifted rhizome sections are no cheaper (based on ADAS experience). However, Huisman & Kortleve[1] have calculated that a system of power-harrowing established rhizome networks and harvesting the

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[1] Huisman W & Kortleve W J (1994). Machanisation of crop establishment, harvest and post-harvest conseravation of *Miscanthus sinensis* ‘Giganteus’. *Industrial Crops & Products.*

pieces with a bulb harvester, can yield enough material from 1 ha to establish a further 30 ha, and can reduce the cost of material to as little as £0.02 per piece. Certainly variations on this method have been employed successfully at ADAS Arthur Rickwood and by the South West Industrial Crops Group. The effect of this reduction on establishment costs is dramatic, and this model has been set accordingly with a propagule cost of £200 per hectare and a planting cost of £150 per hectare. These establishment costs are amortised over the projected lifespan of the crop. However, in this current model, fiscal inflation is not considered.

Fertiliser
The specific nutrient requirements of Miscanthus are still to be determined, but evidence so far indicates that it will not require more than maintenance applications of N, P & K once established. Off-take figures of 7 kg t^{-1} N, 10 kg t^{-1} K and negligible offtake of P are often quoted[1]. Accordingly, the following models assume an annual, post establishment application of 60 kg N, 40 kg P and 80 kg K ha^{-1}. It may transpire that these levels are higher than actually required. Clearly there will be great site to site variation in the fertiliser regime required.

Weed control
The importance of effective weed control is well known[3] [4]. Specific herbicide requirements (or mechanical methods) will vary tremendously from site to site. Data in this model are set at two 'standard' applications of herbicide, one pre-emergence, one post emergence, i.e. £50 ha^{-1} yr^{-1}.

Irrigation
Whilst there is increasing acknowledgement that Miscanthus has a high moisture demand despite a relatively high water use efficiency, it is probably infeasible to consider irrigation a viable economic tool, particularly if the end market is biomass for combustion. Therefore, no allowance for irrigation is included in this model.

Harvesting and Storage
Harvesting costs have been set at the rate suggested by W Huisman (pers comm) based on considerable experience in the Netherlands. UK evidence suggest existing machinery (e.g. CLAAS Jaguar 680 forage harvester with standard Kemper header) will be suitable to conduct the harvesting operation. Storage costs will vary tremendously depending on length of period and rate of decomposition whilst in store, information on this is currently being gathered at ADAS Arthur Rickwood. Choice of harvester technology will depend on the system of final energy production, however, the feedstock quality from existing machinery may not be suitably high. The cost of harvesting has been set at a contractor level of £200 ha^{-1} [5].

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[1] Bullard, M J., Christian, D. G. & Wilkins, C. (1996). The potential of Graminaceous Biomass Crops for Energy Production in the UK: An Overview. *Proceedings of the 9th European Biomass and Bioenergy Congress, Copenhagen, 23-27 June 1996.*

[3] Speller, C. S. (1993) Weed control in Miscanthus and other annually harvested biomass crops for energy or industrial use. *Brighton Crop Protection Conference Weeds*, 2, 671-676.

[4] Bullard, M. J., Nixon, P. M. I., Kilpatrick, J. B., Heath, M. C. & Speller, C. S. Speller. (1995). Priniciples of weed control in Miscanthus spp. under contrasting field conditions. *BCPC Weeds*, Brighton Conference, November 1995.

[5] Nix, J. (1995). *Farm Management Handbook, 25th edition*. Wye College, University of London, U.K.

Subsidies
This model assumes *no* planting or set-aside grant aid, on the basis that current UK policy will not recognize environmental benefits, and will expect all crops to 'stand alone' commercially. However, it is worth noting that some form of subsidy, even with a projected decline in set-aside area, may be available. For example, it is possible that environmental considerations will become more important. The implementation of carbon taxes on fossil fuels may encourage the renewable energy market generally, and biomass crops specifically.

Yield and crop value
The revenue generated by a Miscanthus crop will be determined by these two characters. The present MAFF funded screen of seven sites, EU Network and ADAS Seedcorn physiological studies of Miscanthus are assimilating valuable data on the yields that can be expected throughout Europe. However, there are still likely to be regional and seasonal variations in yield, and as mentioned earlier, the productive life-span of the crop is still unclear. We anticipate that mean yields of 15-20 odt ha^{-1} should be achievable under appropriate conditions.

Crop value is an altogether different matter. In chemical terms, biomass is principally ligno-cellulosic material which, when dry, is highly combustible. Its calorific value is about 16 MJ g^{-1} or approximately one third the value of coal and oil (which are fossilised plant biomass); thus, one kg (d.m.) of biomass is equivalent to approximately 0.4 kg of oil in energy equivalent terms. Given a market value of one tonne of crude oil of £96, the equivalent value of dry biomass is £39. However, unless supported by some form of grant aid biomass is unlikely to attract a higher premium than the cheapest fuel commodity, which at present is likely to be straw, at least in areas where there is a straw surplus. In addition, increasing pressure for NFFO's 4 & 5 to achieve parity in energy supply costs (with respect to fossil fuels) indicates that the market price for the biomass may be significantly less. For example in eastern England as little as £20 t^{-1} is currently quoted for power station-contracted straw supply, although there is likely to be extreme regional variation. The area of set-aside in the EU will also influence the value of residues. For example, with set-aside running at 10% in the UK a shortage of straw for bedding pushed prices up to £60 t^{-1}. In times of surplus it may cost as little as £17 t^{-1}. To be deemed a viable option for the UK farming community Miscanthus will need to be seen to provide a reliable biomass supply to the energy producer at a quality that is superior to alternatives, or at a cost which is significantly lower than alternatives.

Secondary markets, for example, bio-materials and fibre would improve the economics of Miscanthus production, but these are even less developed than the energy market. Direct import substitutes for MDF board production would command a premium price of £80-90 odt^{-1} (J Hague, pers comm). This assumes that the crop fibres are suitable, which may not be the case. A separate study concentrating on identifying potential markets for Miscanthus is underway as part of this project.

Field storage and drying
Evidence so far suggsts that there will be a field storage/drying requirement for Miscanthus, on the basis that 12 month supply to the energy conversion plant will be required and that crop moisture content will not be sufficiently low at harvest. This current model assumes £200 ha^{-1}; standard costs[1] for field storage of cereal straw.

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[1] Nix, J. (1995). *Farm Management Handbook, 25th edition.* Wye College, University of London, U.K.

Conclusions
The economics of Miscanthus production is not static, as information and experience increases, so input costs may reduce. In order that this report has long-term value, response surfaces (Figures 3.1 & 3.2) have been produced for the break-even value of 1 tonne of dry biomass i.e. the selling price required to cover all variable costs. The most uncertain variables have been modeled - yield, establishment cost and plant spacing. It is clear that the major determinant of break-even (variable) costs will be the yield attained from the crop. As the costs of major inputs change these graphs can be used to calculate the new value of the crop and thus the feasibility of production. On the basis of no grant payments, annual mature yields of 20t ha^{-1}, establishment costs of £0.04/plant we can see that the break-even cost is approximately £20.00. Given an energy equivalent value (to oil) of approximately £39, this break even cost is quite high, leaving little potential profit margin (remember this analysis does not include fixed costs or transportation to the factory gate), yet coupled with subsidies, alternative product markets or grant payments it does offer significant hope for the future.

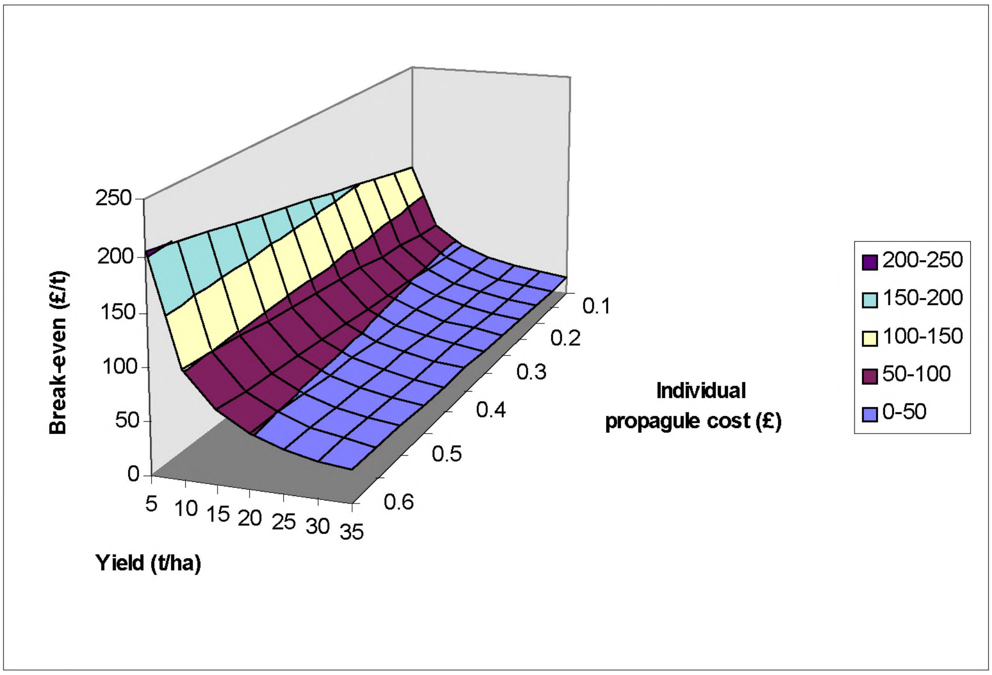


Figure 3.1 Response surface of break-even costs (£/odt) generated by varying yield and establishment cost per cutting assuming a starting density of 10,000 plants per hectare.

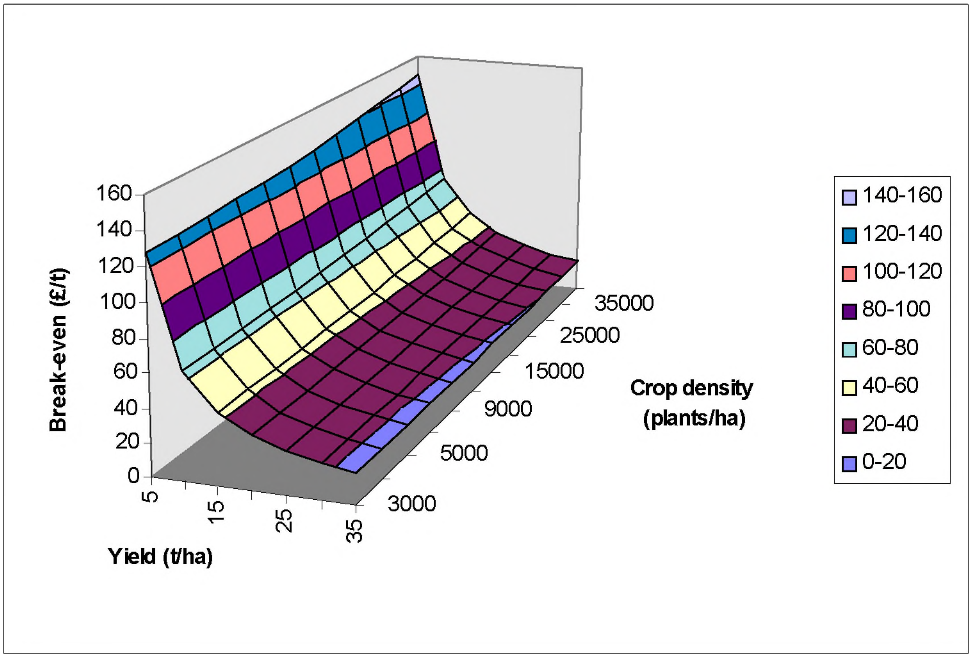


Figure 3.2 Response surface of break-even costs (£/odt) generated by varying yield and planting density assuming an initial cost of £0.04 per plant.

4. EXPERIMENTAL DETAILS AND RESULTS FROM UK COMPONENT OF EUROPEAN MISCANTHUS NETWORK SCREEN OF *MISCANTHUS x GIGANTEUS* Greef et Deu

4.1 Objectives

- To determine the sustainable yield and quality of Miscanthus as a low input agricultural crop at different locations in the EC, with particular emphasis on northern Europe.
- To assess the limitations which low temperatures and other stress factors place on the growth of Miscanthus under European climatic conditions.

Project outline

The EC Network project is comprised of several separate studies, one of which is a replicated field trial which aims to assess the effect of nitrogen fertiliser on the growth and yield of *Miscanthus x giganteus* (see chapter 2). The experiment is duplicated at many sites across Europe; nitrogen rates (0, 60, 120 kg ha^{-1}), plant spacing (0.5m) and plot size (10m x 10m) are all consistent across sites. All experimentation is in accordance with the protocol by Hyperion Ltd who are the co-ordinating organisation.

Origin of plant material

Micro-propagated *M. x giganteus* plants were produced by Piccoplant nurseries, Oldenburg, Germany, during the spring of 1993. These plants were received at ADAS Arthur Rickwood on 19 May 1993, after road and sea transportation which had taken approximately two days. The plants arrived two weeks later than expected. During transport the plants were enclosed in cardboard boxes. On arrival at Arthur Rickwood the boxes were unloaded immediately, transferred to an unheated polythene tunnel, opened, and watered thoroughly. Individual plants were approximately 30cm tall, with 1-3 stems. Roots were enclosed in 6cm^3 peat blocks. The condition of the plants could be described as adequate; a significant proportion were chlorotic, suggesting that they had been deprived of light for more than the two day transit period. A large number of peat modules contained weeds. From the point of delivery until transplanting/dissemination to the other sites, the plants remained under these protective conditions and received regular overhead irrigation. Plants were despatched to Rothamsted on 24 May and to ADAS Rosemaund one week later.

4.2 Planting details

ADAS Arthur Rickwood

The experiment was established after ploughing-out a field of winter wheat. *Miscanthus x giganteus* was transplanted into moist peaty-loam soil on 28 May 1993 using a hand planting tool. Transplants were positioned so that the top edge of the peat pot was approximately 1cm below soil level and the soil surrounding the plants was consolidated by healing-in. Plants were positioned in a matrix, 50cm apart, in accordance with the protocol. In addition, a nursery area was established in spare plots on an adjacent area on 8 June 1993. Immediately following planting the site received 250 cm of irrigation. In the following month (July) the site received a total of 100 mm of irrigation (spaced over 6 occasions).

Nitrogen as ammonium nitrate (34.5%N) was applied at the rates specified in the protocol on 17 June 1993 after the site had been hand-weeded. P & K were not applied in 1993 as the soil had a high index for both nutrients. The site received regular hoeing and hand-weeding and an application of atrazine @ 2.5 l/ha on 16 August. Main weed species were *Polygonum persicaria* (redshank), *Chenopodium album* (fat-hen), *Galeopsis tetrahit* (hemp nettle), *Poa annua* (annual meadow-grass), *Bilderdykia convolvulus* (black bindweed), *Stellaria media* (chickweed),*Viola arvensis* (field pansy) and *Galium aparine* (cleavers).

ADAS Rosemaund
M. x giganteus was transplanted into moist silty clay loam soil on 1 June 1993 using a hand trowel. Transplants were positioned so that the base of the plants was 1 cm below the soil surface. The plants were then heeled-in . An internal headland between blocks was used for ease of spraying and harvesting. Excess plants were planted in a nursery area nearby. Nitrogen was applied at the rates specified on 23 June 1993. P & K was not applied in 1993. Mecoprop was applied @ 2 l/ha on 21 June 1993 to control chickweed (*Stellaria media*)

IACR Rothamsted
M. x giganteus were planted out on 24 & 25 May 1993 using trowels. The plants were watered-in, and received additional water on 26 May and 8 June. Nitrogen was applied at the rates specified in the protocol on 30 June 1993. Weeds identified at Rothamsted included *Chenopodium album, Atriplex patula, Polygonum persicaria, Stellaria media, Senecio vulgaris, Poa* spp. and *Rumex* spp. Plots were hoed by hand in June, but rapid weed regrowth led to the use of herbicide on 22 July. Mecoprop + CMPP (Duplosan) @ 2.5 l/ha and bromoxynil plus ioxynil (Oxytril) @ 1.4 l/ha in 220 l water were applied

4.3 Results

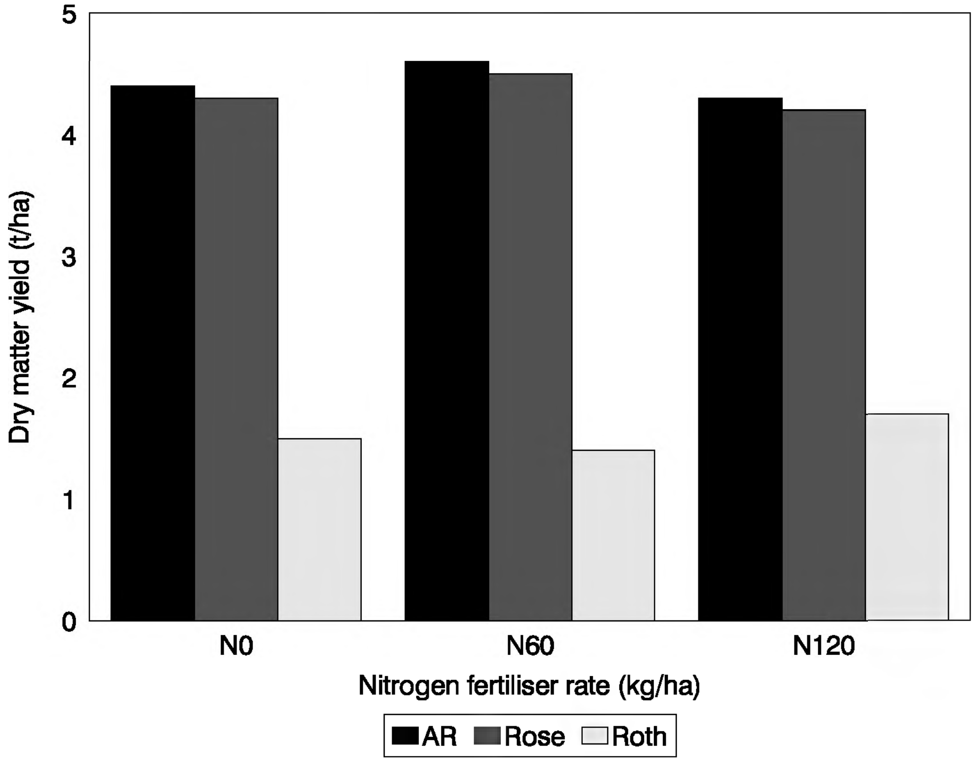
1993/94
Because the growing season was short with small plants being planted in May, dry matter accumulation was low. There were differences in yield between sites. Yield at ADAS Arthur Rickwood and Rosemaund were similar and considerably greater than at Rothamsted (fig. 4.1). Comparison of shoot growth (table 4.1) shows that although differences between shoot height and shoot number occurred the largest difference was in individual shoot weight. The reason for the difference is not clear but may be as a result of differences in water supply.

Table 4.1. Stem length, population and individual stem weight at the end of the growing period. (Means of treatments, rounded values)

	Stem Length cm				Stems per Plant				Weight per Stem (g)		
	N0	N60	N120	SED	N0	N60	N120	SED	N0	N60	N120
Rickwood	120	118	117	2.68	38	44	32	3.81	2.9	2.6	3.4
Rosemaund	165	166	169	1.41	36	36	35	1.27	2.9	3.1	3
Rothamsted	133	133	121	4.38	30	29	33	4.23	1.2	1.2	1.4

Below ground biomass was estimated at Rothamsted on plants receiving 60kg N ha^{-1}. It was found that around 60% of the total biomass (underground and above ground biomass) was in the root/rhizome complex. At Rickwood biomass of the root/rhizome fell from 60% to 30% of total biomass through the growing season. The off take of nitrogen, phosphate and potassium was estimated in harvest samples collected at Rothamsted. This shows that concentrations of major nutrients in the dry matter were slightly greater than would be found in cereal straw. However, the immaturity of the plants should be taken into account and a clearer picture of nutrient off takes will be found in the second or third year after planting.

Figure 4.1 Dry matter yield of *Miscanthus x giganteus* at three sites, 1993.



AR = ADAS Arthur Rickwood
Rose = ADAS Rosemaund
Roth = IACR Rothamsted

4.4 1994/95

Stem development:
A similar pattern of stem production and stem survival was observed at each site. At no site was there found to be much influence on stem number as a result of the amount of nitrogen fertiliser applied. A stem count in late May, (day 150) showed the number of emerging stems was almost identical at each of the sites. This suggests that although stem numbers were fewer on the N0 and N60 plots at Rothamsted in the previous year, a similar number of buds must have been formed on the rhizomes. (fig. 4.2)

By July, a loss of shoots was recorded (fig. 4.2). This may have been as a result of the hot dry conditions that occurred at this time, but is more likely due to self-thinning induced by canopy closure depriving less mature stems of light. Results from Rothamsted show a decline in the rate of dry matter production from this time (fig. 4.3). More stems were recorded on plots at Rosemaund than the other two sites but by the autumn, stem density declined at Rosemaund so that a similar number of stems was found at each site. Stem elongation was greatest at Arthur Rickwood and least at Rothamsted with Rosemaund intermediate. The rate of elongation was similar at Arthur Rickwood and Rosemaund. At Rothamsted the rate of extension declined from an earlier date and average height of stems was about 50cm less than at Arthur Rickwood (fig. 4.4)

Canopy development was measured by leaf area index (LAI). Canopy closure (LAI=4) was reached by mid July at Arthur Rickwood and Rothamsted but at Rosemaund this index was reached about early July. (fig. 4.5) This may reflect warmer conditions in the spring and early summer. At Arthur Rickwood, a marked deviation between treatments started in late July and increased during the autumn. Although leaf area index increased, it did so at a considerably slower rate where nitrogen had been applied especially after 120kg ha^{-1} was applied. Canopy structure and light interception were measured at intervals throughout the season. Interception did not differ between treatments and canopy closure (95% light interception was achieved in mid August).

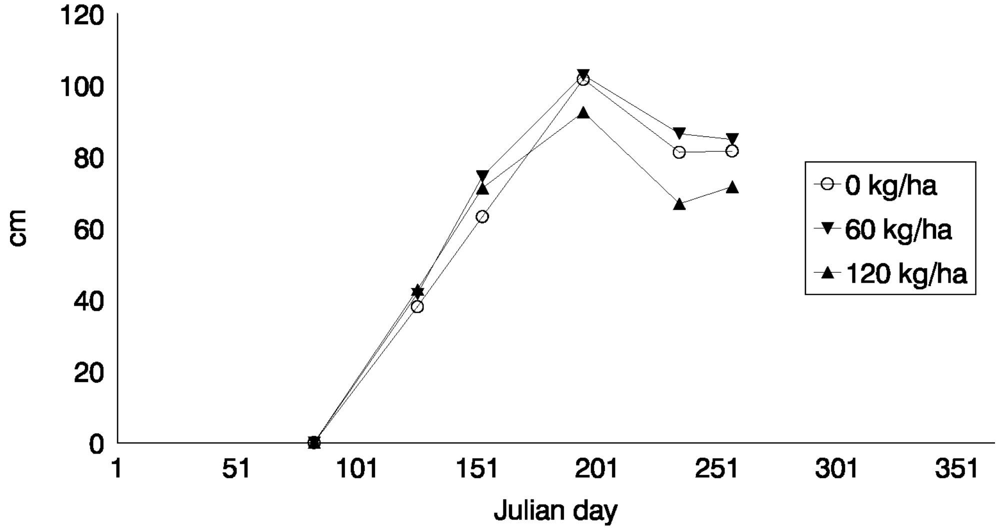
At Rothamsted and Rosemaund LAI declined from late August. This corresponded to canopy closure and shading of lower leaf layers. The dry spell in August caused leaf tip die back and leaf rolling at all sites, even after 50mm of irrigation at Rickwood.

Yield.
Standing crop yields are shown in Figure 4.6 and moisture content at harvest in Figure 4.7. Over the three sites yields ranged between 7-13 t dm/ha and moisture content between 50-55%. No differences between treatments or sites were significant. Chemical analysis, presented as total off-take per hectare for major elements and mg/kg biomass for micro-elements and heavy metals, are presented in Tables 4.2 and 4.3.

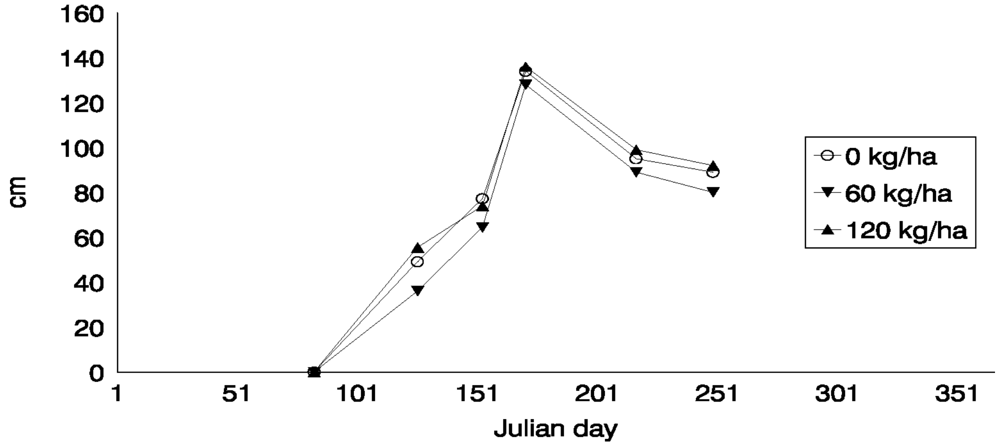
The slightly higher moisture contents at Rosemaund were not explained by harvest date. Percentage moisture content was not influenced by N fertiliser rate.

Figure 4.2 Stem number (per m^2) of *Miscanthus x giganteus* at three sites, 1994.

ADAS Arthur Rickwood



ADAS Rosemaund



IACR Rothamsted

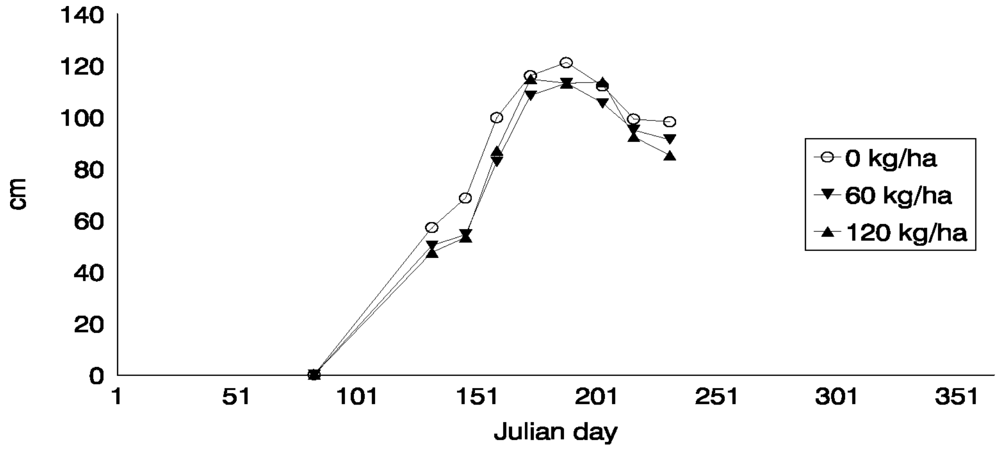


Figure 4.3

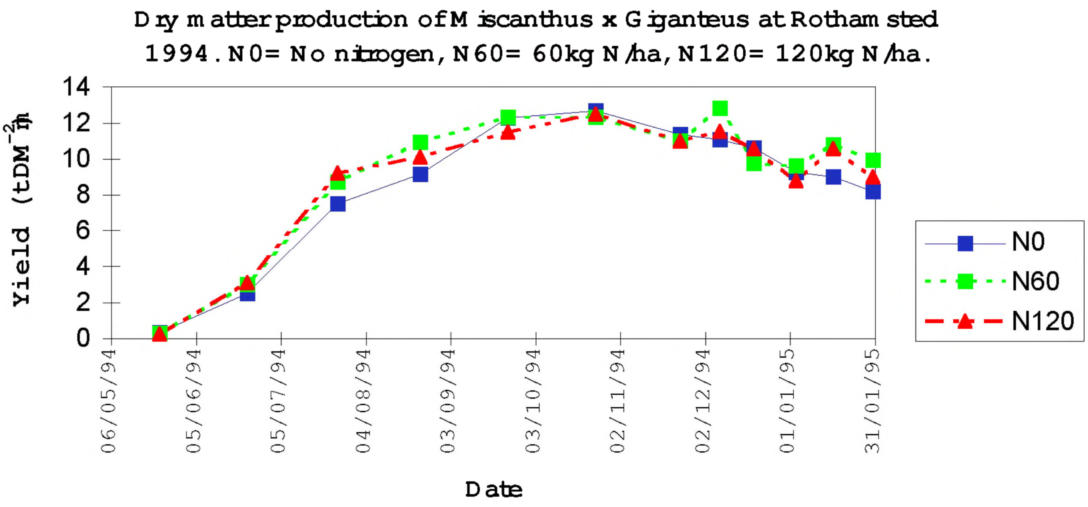


Figure 4.4

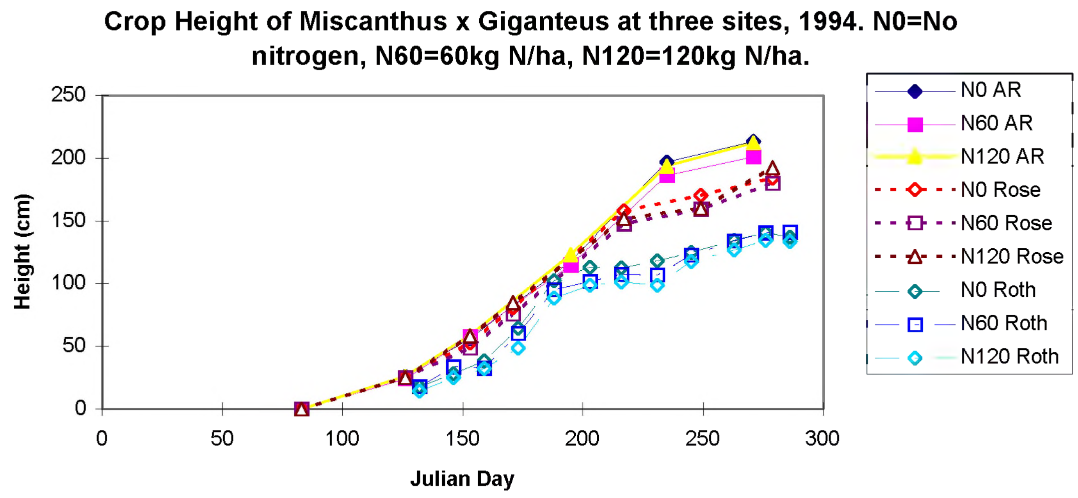


Figure 4.5

Leaf area Index of Miscanthus x Giganteus at three sites, 1994. N0=No nitrogen, N60=60kg N/ha, N120=120kg N/ha.

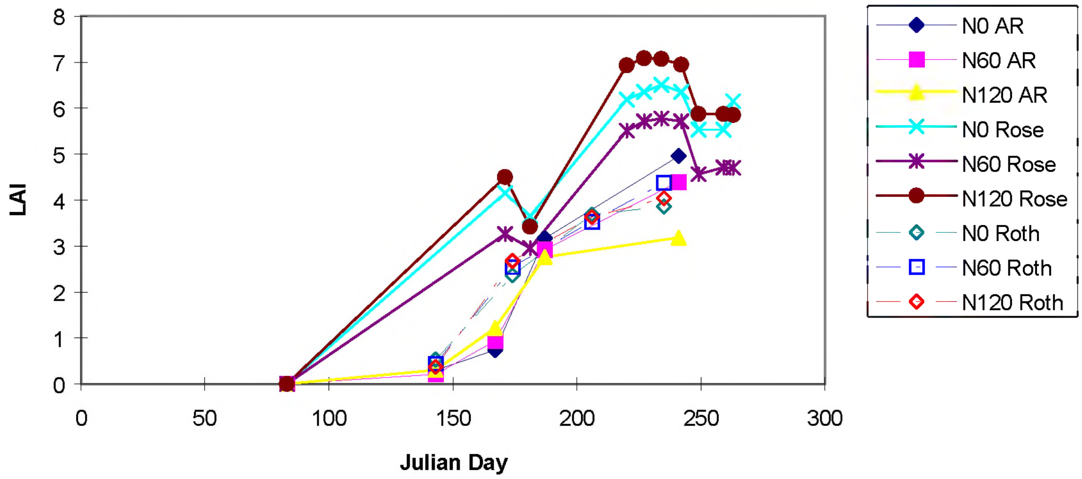


Figure 4.6. Standing crop yield from *Miscanthus x giganteus* at Rickwood, Rosemaund and Rothamsted 1995 (ANOVA indicated no significant differences).

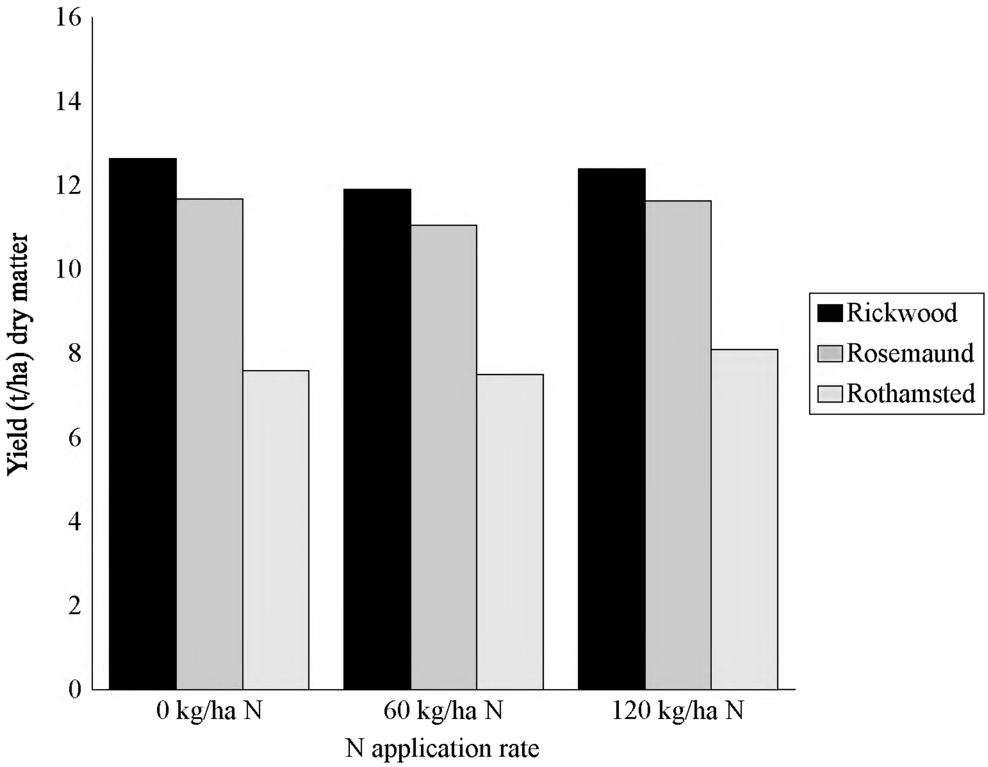


Figure 4.7. Moisture content at harvest (%) of *Miscanthus x giganteus* at Rickwood, Rosemaund and Rothamsted1995.

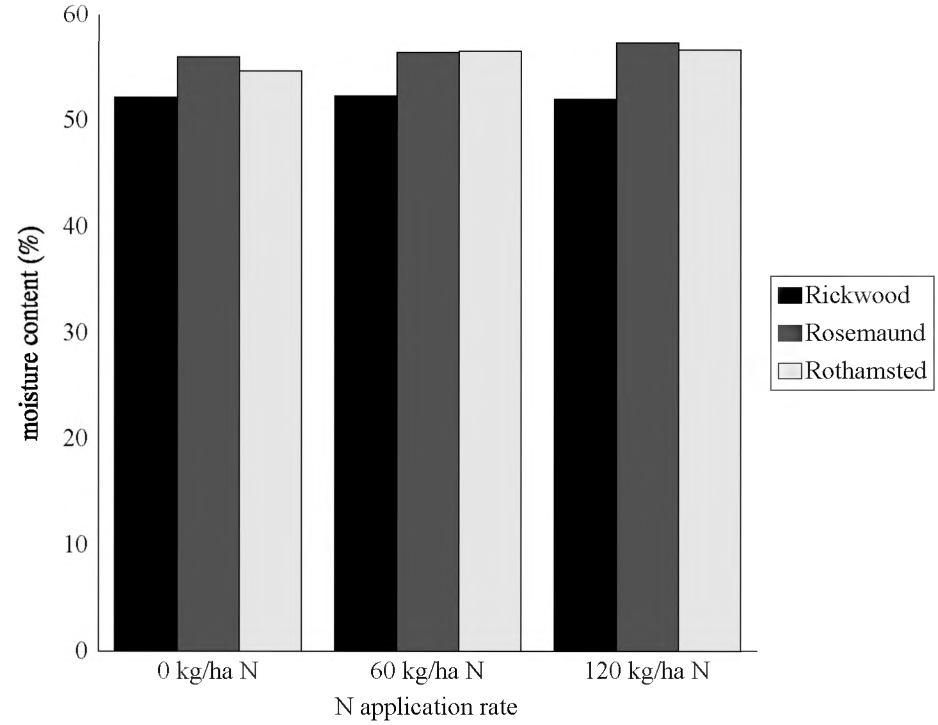


Table 4.2. Nutrient offtake (kg/ha) based on percentage content of sub-samples and harvest means (Rickwood, 1995)

N rate	N	K	Mg	P
0	74	110	9	7
60	76	106	8	6
120	79	114	9	6
SE	2.76	3.53	0.32	0.29

Table 4.3. Micro-nutrient and heavy metal content (mg/kg) harvested material (ADAS Arthur Rickwood, 1995)

N rate	Pb	Ni	Zn	Cd	Cr	Cu	Hg
0	0.63	1.17	15.63	0.09	1.97	2.07	0
60	0.63	1.07	15.17	0.10	1.77	2.32	0
120	0	1.20	18.13	0.087	2.20	2.16	0
SE		0.141	1.328		0.214	0.099	

4.5 1995/1996

Fertiliser application

Ammonium nitrate fertiliser (34.5% N) was applied according to the experimental protocol on 5 April, 10 May and 11 May at Rosemaund, Rickwood and Rothamsted respectively. Potassium was applied at 140kg ha^{-1} on the same date at Rickwood and Rothamsted.

Crop development:

Crop height and stem number on a unit area basis were monitored during the season in the same way as 1994. At Rothamsted the crop grew more rapidly and taller than in 1994. At Rickwood crop height (Figure 4.8) equalled the maximum heights achieved during 1994. The maximum height achieved at Rickwood was 2.1m (September). The amount of Nitrogen fertiliser applied did not influence on stem height or on the number of stems produced. Stem number/m^2 (Figure 4.9) attained maxima of 174 at Arthur Rickwood (June), before self-thinning to 100 stems. The peak stem number was achieved just before complete canopy interception (July), and indicated the point at which competition for light became a factor governing crop morphology. As in the previous year, canopy light interception and canopy development (figure 4.10) did not differ accordingly to N application rate. The first heavy frosts occurred in late October / beginning of November and thus the plants started to senesce earlier than the previous year. During 1995 at Rothamsted, more shoots emerged than in previous the year, but more were lost (43%), hence a lower number of shoots were maintained. The peak shoot number was reached earlier than in 1994. All shoots lost at all sites were 'juvenile'.

Rickwood and Rothamsted dry matter increment throughout the season was more rapid than in previous years reaching a maximum in early-mid August at Rothamsted (Figure 4.11). All sites were typified by some renewed leaf growth in September following the first rain after the drought. However, no further inter-nodal lengthening was noticed, suggesting that internode extension in Miscanthus is controlled by photoperiod or temperature.

Yield

Crops were harvested between mid February and early March. Standing crop yields were not significantly affected by fertiliser treatment. Yields(standing crop plus leaf litter) at the sites ranged between 13.02 (Rothamsted) and 14.33 tonnes per hectare (Rosemaund). Rothamsted and Rosemaund yields represented a significant increase from the preceding season. Rickwood yields were similar to the preceeding year.

Biomass moisture content at Rickwood and Rosemaund averaged 38% and 47.5% respectively, a mean improvement of approximately 18% 5%, respectively, on the previous year. Moisture content at Rothamsted averaged 56%, higher than 1994/5 - possibly because of an earlier harvest.

Figure 4.8. Crop height (cm) of *Miscanthus x giganteus* at Rothamsted & Rickwood, 1995

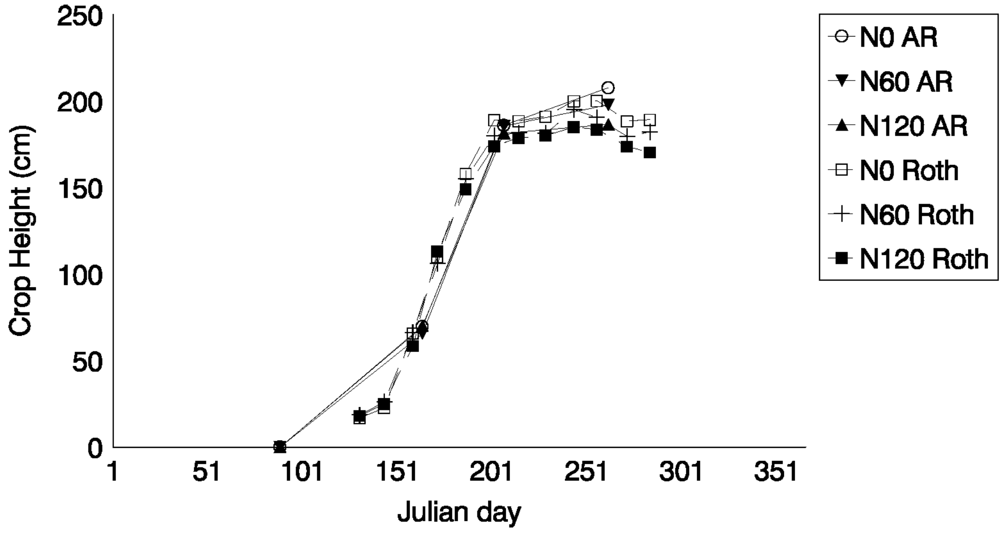


Figure 4.9. Stem number/m2 at Rothamsted & Rickwood, 1995

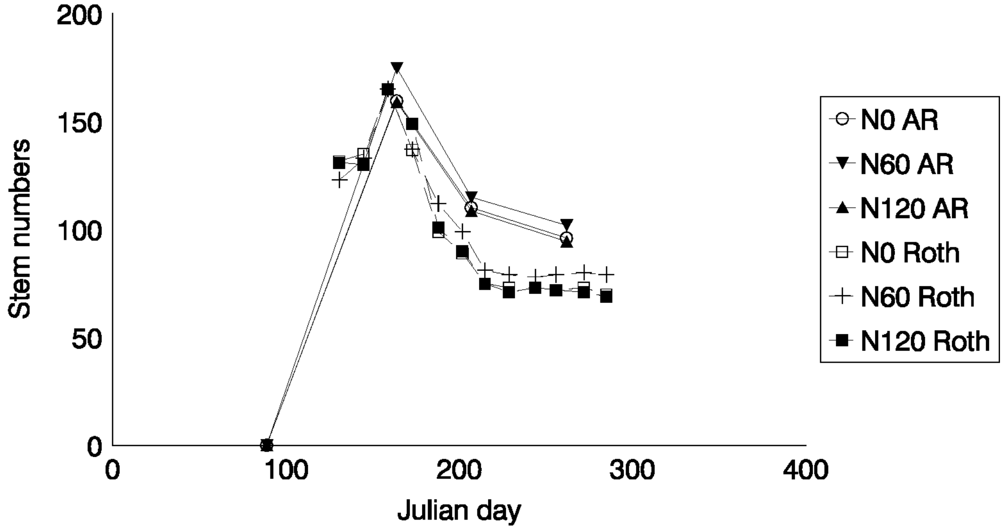


Figure 4.10. Canopy development (measured as green area index, GAI) at Arthur Rickwood and Rothamsted, 1995

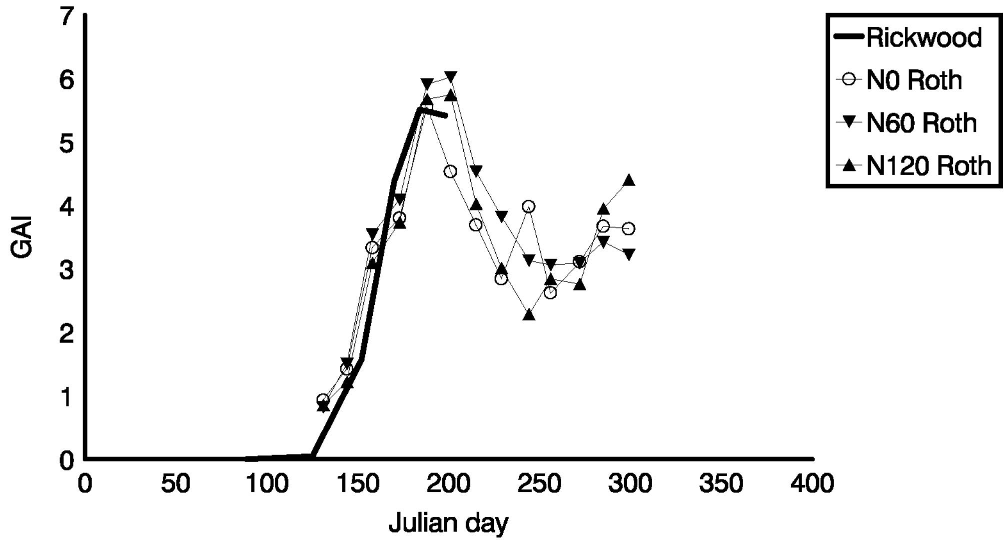


Figure 4.11. The above ground biomass productivity (t/ha) of M. x *giganteus* at Arthur Rickwood and Rothamsted, 1995.

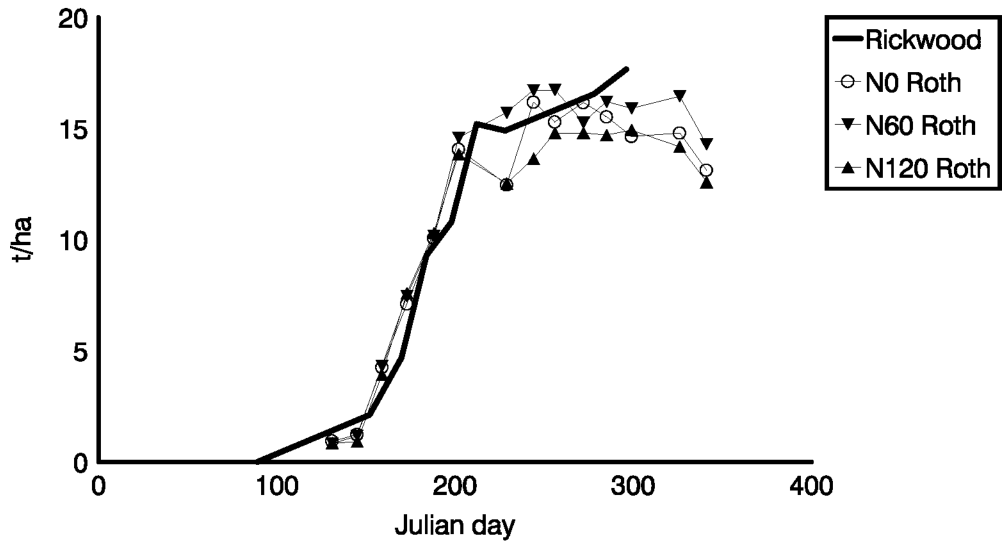


Figure 4.18 Harvest yield, components of yield and moisture content *of Miscanthus x giganteus* harvested at Rothamsted, February 1996.

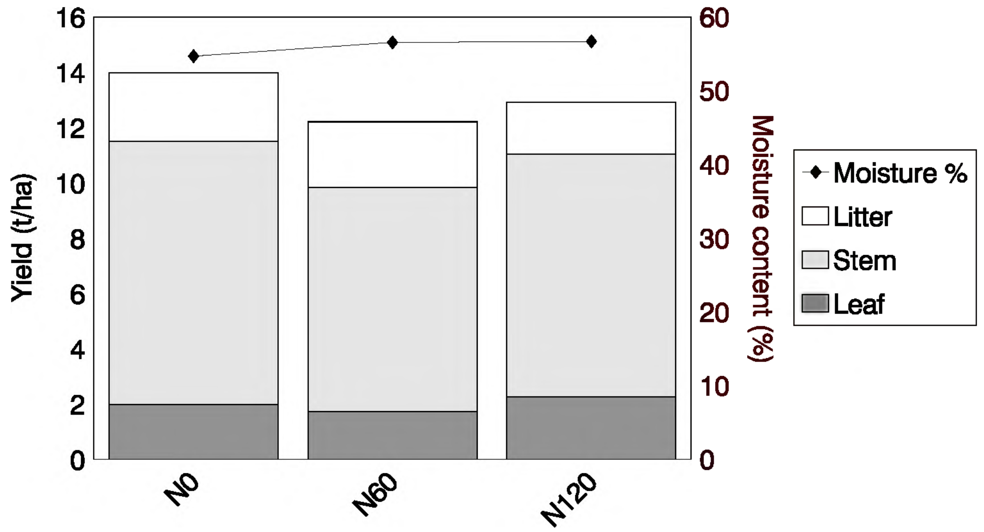


Figure 4.19 Harvest yield, components of yield and moisture content of *Miscanthus x giganteus* harvested at Rickwood, February 1996.

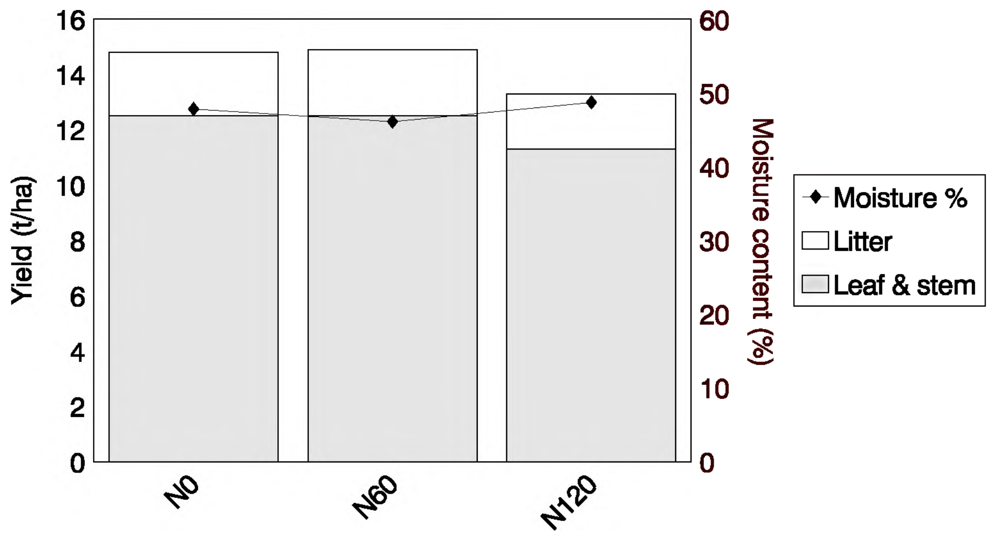
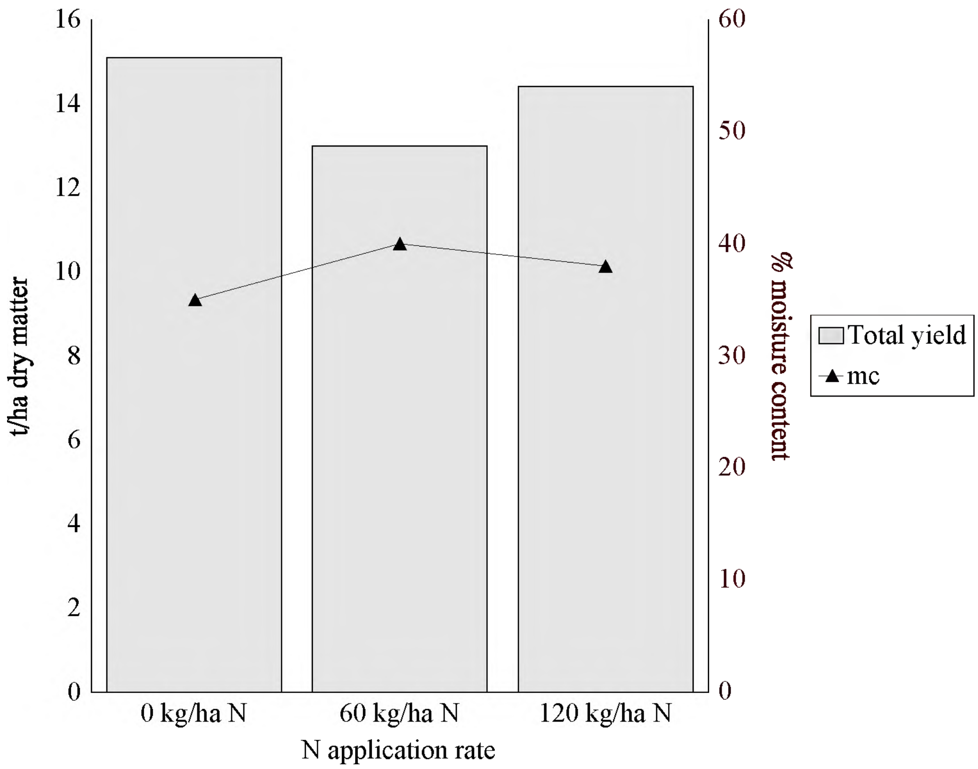


Figure 4.20 Harvest yield, components of yield and moisture content of *Miscanthus x giganteus* harvested at Rosemaund, March 1996.



4.6 General comments on 3 years of Miscanthus development

1993/4

Following transplanting into moist soil at all sites, plants stayed healthy in appearance for the next 48-72 hours. Thereafter, they experienced a severe transplanting check which at Rickwood and Rothamsted was exacerbated by moisture stress caused by strong, drying winds. Foliage paled and took on a purple coloration extending from the base of the shoots and leaf blades. In addition to the shock caused purely by moving from protected conditions, the culture media and peat-pot allowed the roots to desiccate very quickly. At all sites, the plants required irrigation or hand watering to keep them alive. The plants gradually recovered and by the middle of the first season were well established. Our observations on the plants' initial performance suggest that *M. x giganteus* responds to stress by sequestering above ground nutrients back into the root system. This leads to the purple coloration of the leaves and their eventual death. There then follows a period of consolidation when the root system develops; in the current circumstances this meant the development of roots through the peat pot. Only once these roots have developed will the plant start to shoot vigorously.

The problems encountered at planting suggest that the micro-propagating process needs to be refined. Either the plants should be removed from the peat pots, or the plants should be at an earlier stage of development. Alternatively, the plants need to be produced in a growth-media that does not dry out so readily. Control of weeds was seen to be essential in the initial stages. This is discussed in more detail in the environmental impact assessment section.

1994/95

Growth in the second season (measured in terms of canopy height, development and biomass accumulation and partitioning) was superior to that of the establishment season. Whilst

Miscanthus looks to be a promising biomass species, it appears that micro-propagation is not the most appropriate method of culture. In a separate study rhizome-derived plants appear to be at least one season more advanced (in terms of height and dry matter production) than micro-propagated derived ones. In addition, there is increasing evidence that a density of 4 plants/m^2 is too high both in terms of the prohibitively expensive starting costs and the rapid rate at which yields acquire parity. One or two plants/m^2 may be more appropriate. The mid-season response to moisture stress at all sites indicates that in precipitation deficient years, biomass production may be limiting. It is yet to be seen what the broader implications are for the long term viability of Miscanthus production in the UK.

1995/96

Productivity data for 1995/96 must be viewed in the context of one of the most severe summers on record. Unseasonally late frosts followed by the long drought would have stressed most crops.

Whilst Miscanthus showed moisture stress symptoms from July until September (leaf roll necrosis, leaf fall) the unirrigated crops nonetheless survived and initiated fresh growth following rainfall. Against this meteorological background, a yield increase (over the previous year) at Rothamsted and Rosemaund and a stable yield at Rickwood are significant attributes for this plant.

We are not yet in a position to decide whether the crops have reached their physiological (and therefore yield) maturity. Evidence from older crops established from rhizome plantings suggests that peak yields and physiological maturity may require 1-2 further years growth.

Preliminary measurements of nutrient offtake also suggest that this crop will require very low levels of fertiliser application after establishment. Evidence so far suggests that it is imperative that weed control (either chemical or mechanical) is conducted successfully on newly planted crops and every subsequent spring, otherwise yield potential will be severely reduced (this is described in more detail in section 8). Whilst pests and diseases have not yet proved to be a significant problem, vigilance should be maintained, particularly if the cropping area increases. ADAS and Rothamsted have published widely on Miscanthus over the last 3 years; a full reference list is provided at the end of this report.

To summarise, ADAS and Rothamsted have found evidence in the last three seasons to suggest that Miscanthus is a suitable crop for the UK. Whilst many caveats exist (yield profile through time, longevity, climatic range, plant breeding opportunities, economics) the full potential of the crop can only be realised after further, targetted, funded R & D to address these questions. Topics for further research are discussed in section 9.

5. HEAVY METAL UPTAKE BY MISCANTHUS FROM CORNISH SOILS POLLUTED BY METALLIFEROUS MINING

As part of the CEC AIR3 Miscanthus Productivity Network, the growth and pollutant uptake of Miscanthus grown on soils and mine waste polluted by copper, zinc and arsenic was studied in pot trials over a two year period. Data from Miscanthus grown on a polluted acid brown earth was compared to that of Miscanthus grown on an unpolluted acid brown earth and from soilless compost. In addition, the effects of composted sewage sludge, lime and NPK application on soils and mine waste were investigated. The aim of the study was to acquire information on the uptake of pollutants by Miscanthus and hence, the environmental implications of combustion of material grown for energy production in polluted areas. This was done by observing (a) the soil-plant pollutant relationships, (b) the seasonal variation in heavy metal uptake by Miscanthus and (c) the effects of inorganic and organic fertilisers on yield and metal uptake.

As a general rule, plant uptake of various metals is related to a number of soil physical and chemical parameters including total concentration of the metal. In these pot trials uptake of copper, arsenic and zinc in the above ground biomass was slightly lower in the Miscanthus grown on unpolluted soil and soilless compost than on polluted soil. However, Miscanthus grown on mine spoil, although growth was inhibited, did not show enhanced metal uptake. Ashing of Miscanthus at 400 °C gave a residue with 200 µg /g Cu, 300 µg/g As and 500 µg/g Zn. Copper and arsenic concentrations in the ash were similar to those in airdried soil but zinc concentration was 60% higher than that of the soil. The major nutrient content of the ash would make it a valuable amendment to be used in minewaste reclamation.

Although variation in uptake of copper, arsenic and zinc between replicates was large there appeared to be a slight decrease in arsenic and copper content of Miscanthus between January and February and a decrease in zinc content between December and January. These decreases occurred when the plants were senescent. Uptake of copper, arsenic and zinc was generally higher in the second year harvest than the first.

The effect on yield and metal uptake of applications of inorganic fertiliser (NPK) with and without lime was compared to the application of sewage sludge with and without lime. Lime is a standard treatment to decrease the plant availability of heavy metal cations in polluted soils but is unlikely to have an ameliorating effect on soils containing arsenic which will occur in the soil solution as an anion. Lime increased the yield on both the soils and minewaste (the soils being acid brown earths and the mine waste being highly acidic) but was not observed to reduce the metal uptake of the Miscanthus. Although inorganic fertiliser increased the yield on soils and mine waste, the addition of lime reversed this effect on soil although giving a large increase in yield on mine waste. Yield response to sewage sludge was positive on soils and mine waste and appeared to be a valuable fertiliser for soils growing Miscanthus. However, when applied to mine waste, although the initial yield response was positive, the plants were unable to survive the first winter. No treatment made a large difference to the metal uptake of the Miscanthus.

In summary, preliminary conclusions to be drawn from the pot trials investigating growing Miscanthus on polluted soils are as follows:

Uptake of copper, arsenic and zinc by Miscanthus from various substrates was not wholly related to total soil concentrations.

Metal contents of the above ground biomass of Miscanthus decreased in late winter/early spring.

Inorganic and organic fertiliser treatments increase yield of Miscanthus, with sewage sludge being an effective fertiliser. However, metal uptake did not appear to be greatly affected.

Obviously, it is necessary to substantiate these initial pot trial results with field trial data in the future. In areas in which Miscanthus ash may contain excess heavy metals, monitoring of heavy metals might be advisable alongside moisture monitoring in the period up to harvesting to ensure that the crop metal content has decreased along with the moisture content.

In a crop where additional costs of inorganic fertiliser application are probably not economically acceptable, sewage sludge is a valuable and cost effective alternative for soils. The use of sewage sludge as an ameliorant for mine waste should be investigated furthur with regard to times and rates of application for projects involving Miscanthus planting.

6. PLOT EVALUATION OF A RANGE OF POTENTIAL ENERGY CROPS

6.1 Switchgrass *(Panicum virgatum)*

Replicated trials were established at Rickwood and Rothamsted during 1993.

6.1.1 Rickwood

Twenty four individual plots comprising four varieties, two N rates (0 & 60 kg/ha) and three replicates were established. Seed was drilled at 10 kg/ha on 5 May 1993. Seedling emergence was extremely slow and patchy. Manganese was applied on 30 July at a rate of 4 kg/ha in 250 l water. On 17 June 1993 Starane 2 (0.5l/ha) plus Briotril (0.3l/ha) was applied as a tank mix in 250 l water. Although the weeds had attained an advanced growth stage by this time, the herbicide did scorch some of the switchgrass, indicating that earlier herbicide application would have been inappropriate. On 17 July the same herbicides were applied but the rates were reversed. Full control of the weeds was not achieved. The experiment at Rickwood was discontinued at the end of 1993 due to extremely poor germination rates (Table 6.1) and strong weed competition.

Seed weights varied greatly within and between varieties. Accordingly, sowing at a standard seed rate of 10 kg/ha gave rise to widely varying potential establishment densities. At Rickwood the scores of plant emergence (Table 6.1) indicated that none of the varieties had achieved more than 15 per cent emergence.

Table 6.1 Establishment of switchgrass varieties at the two experimental sites.

	IACR Rothamsted		ADAS Arthur Rickwood	
Variety	Emergence/m^2	% success	Emergence/m^2	% success
Cave-in-rock	283.7 a,b*	47	37	6
Atlantic	125.4 d	21	20	3
Kanlow	188.9 c,d	23	66	8
Pathfinder	285.7 a,b	56	78	15
Sunburst	218.7 b,c	46		
Forestburg	267.1 a,b	39		
Nebraska 28	275 a,b	39		
Dacotah	301.2 a	44		
Mean		39		
5%-LSD	67.9			

* Values that do not share a common letter differ at the 0.05 probability level.

At Rothamsted the seven varieties of panicum and one panic grass were drilled on 12 May 1993 in randomised blocks with three replications and two rates of nitrogen, control and 60 kg N ha^{-1}. Emergence counts were taken on 28 June, showing a mean plant population of 16 m^{-2} with a range of 8 to 26. Nitrogen was applied on 30 June. Due to excessive weed growth Starane at 0.3l ha^{-1} was applied on 2 July, followed by Duplosan NS CMPP at 2.5 l ha^{-1} and Oxytril CM at 1.4 l ha^{-1} on 22 July 1993.

The plots were harvested on 14 December 1993, with two 0.91m x 1.98m cuts taken across each plot, leaving 2-3 cm of stubble. The yields are illustrated in fig 6.1. The mean yield from the N0 and N1 plots was 1.65t ha^{-1} and 1.58t ha^{-1} respectively. Two varieties, Kanlow and Pathfinder gave significantly higher yields from the N0 treatment, possibly due to inter-plant competition as a result of applying nitrogen. Nutrient uptake measurements showed little difference between varieties at harvest, and hence total uptake reflected yield. Mean results are given in table 6.2.

Figure 6.1

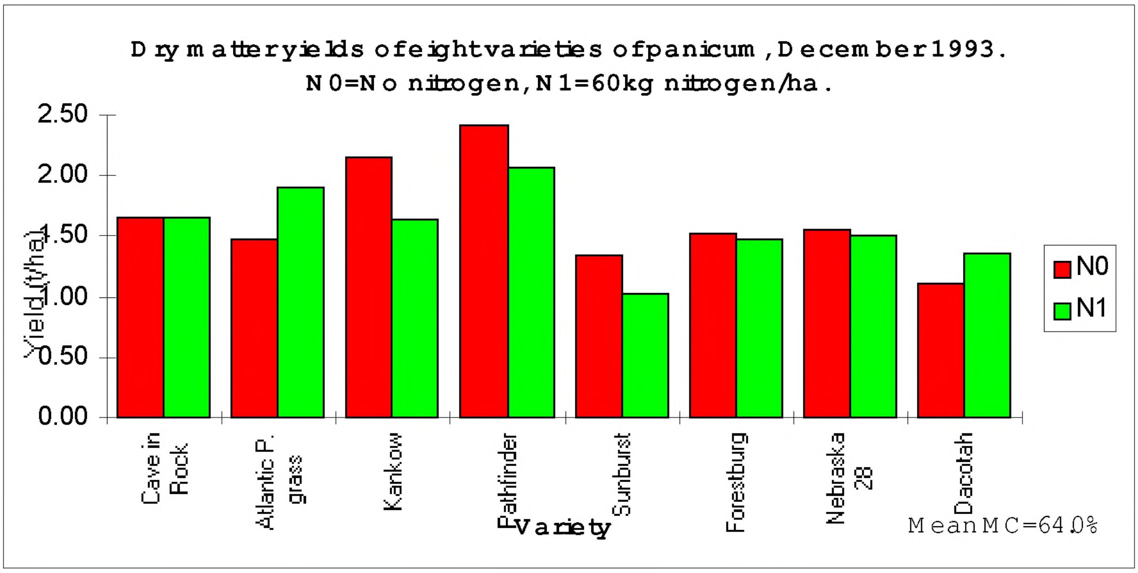


Table 6.2 Nutrient content at harvest, kg ha^{-1}.

Treatment	Nitrogen	Phosphorous	Potassium
N0	30.18	3.28	15.49
N1	28.68	3.06	13.72

The reason for no effect from the applied nitrogen is probably high residual soil nitrogen levels, as a result of a previous crop of beans. Soil samples to 90cm in August at the site showed total nitrogen levels of 200kg ha^{-1}, with 80 kg in the top 0-30 cm layer. The moisture content of biomass at harvest was high (64%), due to the crop being immature. Measurements of lignin, hemi-cellulose, cellulose, ash and hot water solubles and ash were made on the harvested samples and showed little variation between varieties, or treatments. Mean percentages are compared with data from *Miscanthus* grown at the same site in table 6.3. The composition of panicum is similar to Miscanthus, but the lignin and ash content is lower.

Table 6.3 Analysis of composition of *Panicum* and *Miscanthus x giganteus* grown at Rothamsted. % basis.

Crop	Lignin	Hemi-cellulose	Cellulose	Ash	Hot water solubles
Panicum	17.17	32.81	25.39	1.26	21.00
Miscanthus	16.00	31.02	27.54	3.99	18.26

1994/95 Season.

The plots were sprayed with paraquat (Gramoxone) at 3 l ha^{-1} on 6 January 1994, followed with simazine (Gesaprin) at 3 l ha^{-1} on 2 February while plants were dormant.

Soil samples taken in April 1994 showed a total of 96kg N ha^{-1} in the top 90 cm, with 45kg in the top 30 cm, with no significant differences between treatments.
New shoots started to emerge in late April, and plots were scored for emergence on 5 May using a scale of 0-9, with 0 for no visible growth and 9 for rows complete and clearly defined with plants around 10 cm tall. Varieties Atlantic panic grass and Kanlow had failed to emerge and Dacotah was the most forward. The mean score for the N0 treatment was 2.92, with 2.88 for the N1 plots, indicating no effect from the treatment in the previous year. On 12 May 60 kg ha^{-1} of nitrogen was applied to the N1 plots. Stem counts taken on 13 June, showed a mean of 615 m^{-2} for N0 and 662 shoots m^{-2} on N1 plots. Again, Atlantic Panic grass and Kanlow showed no significant growth and were not counted.
All plots were sampled on 13 September, when it was judged that maximum growth had been reached, and yields are shown in figure 6.2. The mean yield of N0 plots was 8.12 t ha^{-1}, and 7.82 t ha^{-1} from the N1 plots, again showing nitrogen to have a negative but not significant effect. As in 1993, Kanlow and Pathfinder showed significantly higher yields from the N0 plots. Stem counts in September showed that for each variety the higher yield came from the treatment with the higher stem count. Mean stem counts were 930 m^{-2} from N0 plots and 912 m^{-2} from N1 plots, 50% higher than the counts taken in mid June. Atlantic Panic grass and Kanlow which had not emerged by mid June still managed respectable yields by September, with only three months growth. Mean moisture content was 62%, lower than in December 1993. Plant height was measured on 19 September and ranged from 70 to 123 cm, with a mean of 107.9 cm for N0 plots and 106.3cm for N1 plots. Dacotah was significantly shorter, despite showing the most vigorous growth in the spring. The other varieties ranged between 100 and 123 cm.

The plots began to senesce in October, with Dacotah the most advanced. Atlantic Panic grass and Kanlow had not senesced completely by February 1995. As the varieties became ready for harvest they were sampled at monthly intervals for yield and moisture content. Results are given in figures 6.3 and 6.4 respectively. Kanlow was harvested in February. Yield was 5.8 t and 5.1 t/ha for the N0 and N1 treatments respectively. The moisture content of the crop was 46%. It can be seen that the yields of varieties had declined since the September sampling. Segregation into components of yield showed the yield of stems to be twice that of the leaves.

Figure 6.2

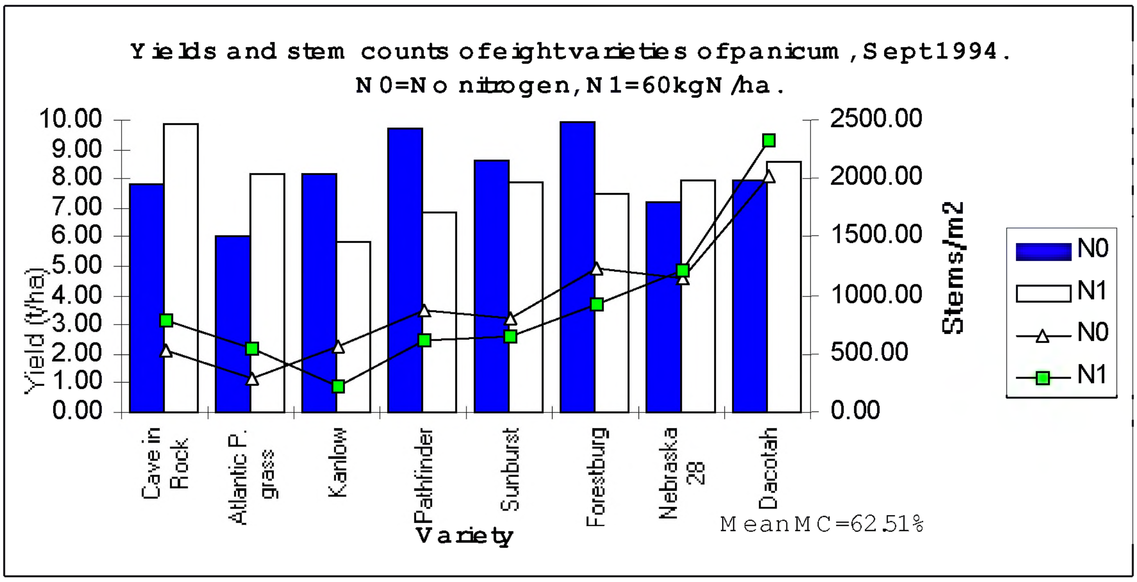


Figure 6.3

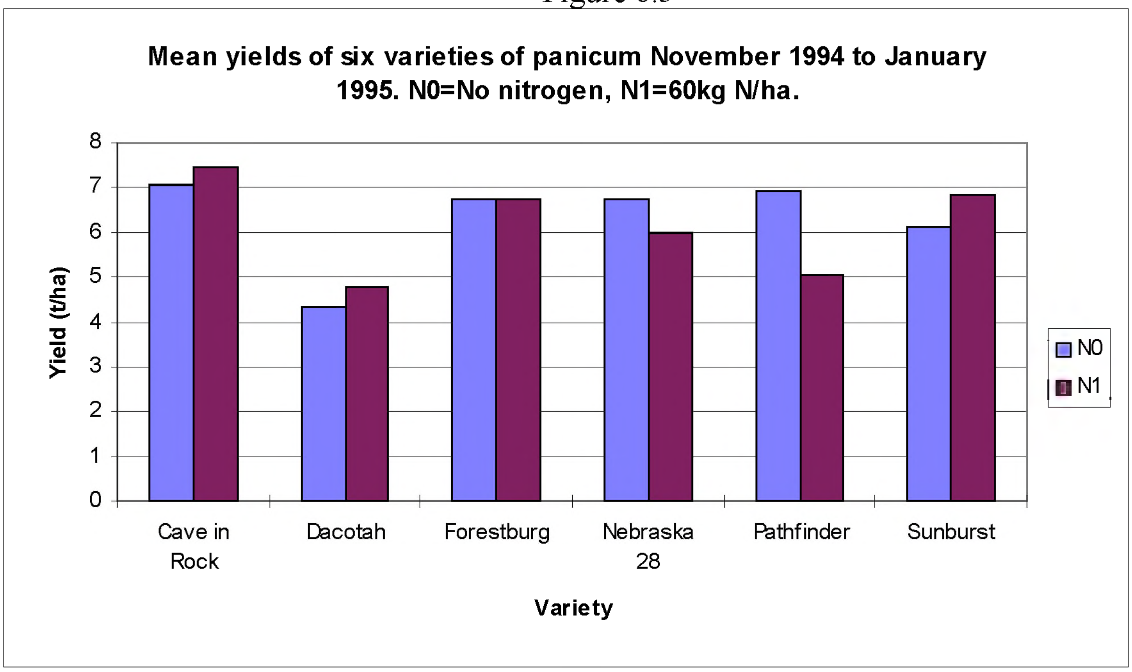
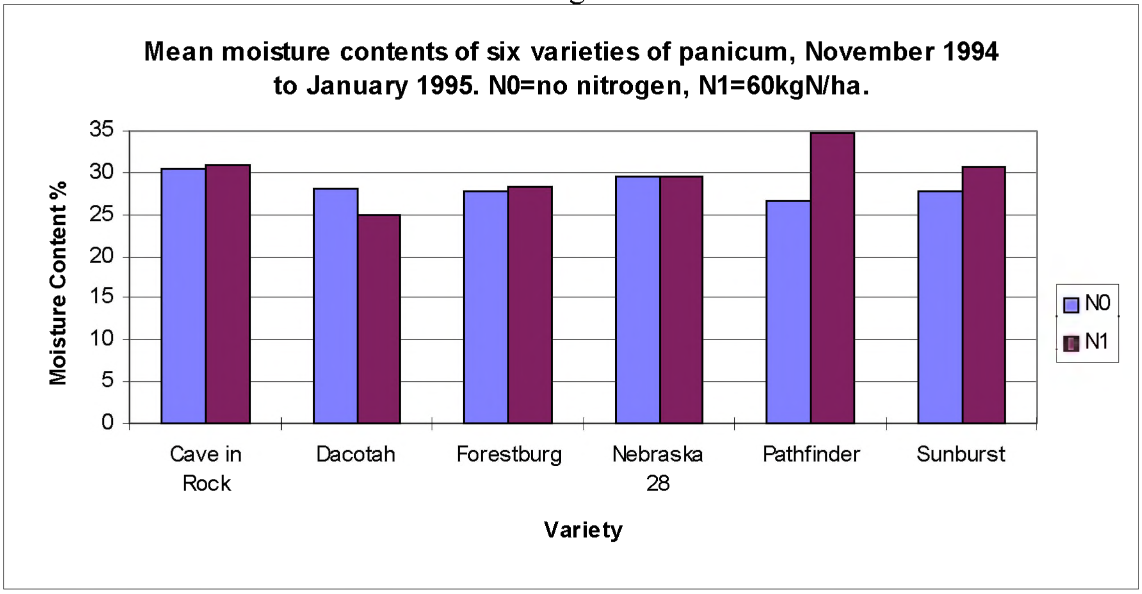


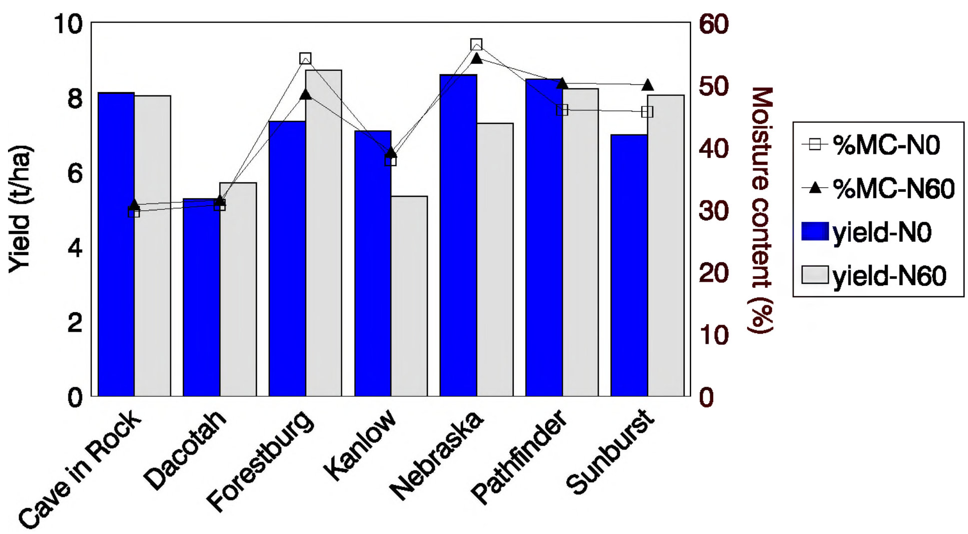
Figure 6.4



1995/96 Season

The crop once again emerged in late April. Plots were sprayed with a tank mix of Oxytril CM (@1.4l/ha) and Duplosan CMPP (@2.5l/ha) on 2.5.95 and again on 22.6.95. N was applied on 15.5.95 at 60kg N ha to the treatments receiving N. Final harvests were timed with the phenological cycle of the individual varieties and harvest areas were 8 rows x 1m cut by hand. There was not such a range of harvest dates between the varieties as the previous year. Yields were higher than these of the previous year (figure 6.5). The variety Atlantic was eliminated from the results due to poor emergence. The relatively high moisture contents were due to poor weather during harvest.

Figure 6.5. Yield (SED 3.215) and moisture content (SED 0.529) of seven varieties of Panicum at harvest 1995/6



6.2 *Miscanthus sinensis* Goliath

Micro-propagated plants were delivered from Rebeschule Steinmann nurseries, Sommerhausen, Germany, on 7 June 1993. Delivery was approximately one month later than preferred. The plants were in reasonable condition, and noticeably different to the *M. x giganteus* which had arrived earlier. The leaves of the Goliath were much finer and also darker green. Planting took place on 9 June at Rickwood and 10 - 15 June at Rothamsted. Both trial sites were hand-weeded frequently, and atrazine (@2.5 l/ha) was applied at Rickwood on 16 August. Nitrogen was applied to treatments at 0 or 60 kg/ha on 15 July at Rothamsted and 12 August at Rickwood. The experiment received a high level of irrigation in order to ensure successful establishment.

Results

Establishment at both sites was in excess of 99%. However, crop development was extremely slow during the subsequent season (tables 6.4 - 6.6). At both sites severe winter kill occurred and prevented any experimentation in 1994/5. At Arthur Rickwood 90% of plants died, and 66% mortality was recorded at Rothamsted. At both sites, the remaining plants were replanted in 1995 in new plots, and establishment was very successful.

Table 6.4 Performance of *M. sinensis* Goliath at Rothamsted

	27/8/93		3/11/93	
	shoot number per plant	plant height (cm)	shoot number per plant	plant height (cm)
0 kg ha^{-1}	3.3	25.7	7	44.7
60 kg ha^{-1}	4.3	20.8	7	40.1

Table 6.5 Performance of *M. sinensis* Goliath at Arthur Rickwood

	29/7/93		30/9/93	
	shoot number per plant	plant height (cm)	shoot number per plant	plant height (cm)
0 kg ha^{-1}	3.7	39.9	11.7	100
60 kg ha^{-1}	3.3	40.2	9.3	94

Table 6.6 Yield (t/ha) & moisture content of above-ground biomass of *M. sinensis* Goliath

	Yield Rickwood	Yield (t/ha) Rothamsted 18/1/94	Moisture content Rickwood 29/11/93	Moisture content Rothamsted 18/1/94
0 kg ha^{-1}	<0.1	0.27	46.4*	64.5
60 kg ha^{-1}	<0.1	0.24		64.4
SED		0.111		2.66

*Non-sample area plants - pooled mean over N treatments.

6.3 *Sweet sorghum (Sorghum saccharatum) cv. Korrall*

The trial consisted of a crop area of 24m x 18m, which contained six 6m x 6m plots consisting of two N treatments (0, 60 kg/ha) and three replicates. Seed was drilled at Rickwood at a rate of 217,000/ha on 7 May 1993, and at a rate of 10 kg/ha on 4 June at Rothamsted. Field germination at both sites was only 20 per cent (approximately). On 16 June the trial at Rickwood was gapped-up using glasshouse-cultured sorghum. A tank-mix of Starane II (Mecoprop + CMPP @ 0.3 l/ha) and Biotril (bromoxynil + ioxynil @ 0.5 l/ha) was applied on 17 June at Rickwood. Duplosan @ 2.5 l/ha plus Oxytril CM @ 1.4 l/ha was applied at Rothamsted on 13 August. The sorghum at Rickwood received manganese and irrigation on the same dates as the Miscanthus Goliath (above). Nitrogen was applied on 29 June and 20 July at Rothamsted and Rickwood, respectively.

Results

Strong winds during mid-October caused severe lodging in the Sorghum at Arthur Rickwood. Consequently the crop was harvested early (20 October), and had a high moisture content. Sorghum was harvested on 15 November at Rothamsted. Yield and moisture content at harvest for 1993 are presented in table 6.7. Yields were low, moisture contents were high and in addition the crop had established extremely poorly. Consequently the species was considered unsuitable and further experiments were not planned. However, due to the interest in this species in other areas of Europe, a small 5m x 5m area was sown at Rickwood on 16 May 1994. Seed was sown by hand in 25cm rows spaced 10cm apart. Once again extremely poor germination ensued (c.20%) and this trial was also abandoned.

Table 6.7 Yields of *Sorghum saccharatum*

treatment	Arthur Rickwood			Rothamsted		
	Plants/m^2	yield (t ha^{-1})	moisture content (%)	Plants/m^2	yield (t ha^{-1})	moisture content (%)
0 kg ha^{-1}	-	7.97	82.6	21.8	1.27	72
60 kg ha^{-1}	-	8.01	83.2	17.8	0.99	70.4

6.4 Screen of Whole Crop Cereals

In addition to the quest for new species for biomass production, some interest has been shown in growing conventional species for biomass, since the agronomy and cultural practices for these are far better demonstrated. Notwithstanding the philosophical problems associated with 'burning food', whole crop cereals may be unsuitable because the premium yields attained in current arable farming are primarily due to high input - high output agronomic regimes. This could not be justified economically when the harvested commodity might only command £20/tonne as a fuel.

The yield potential of rye (*Secale cereale* cv. Amundo) was examined at Rothamsted and Rickwood. In addition, to assess the yielding capability of a selection of candidate whole crop cereals, particularly in view of comparing yields on one site with those of the other candidate species, a multifactorial experiment was established at Rickwood during autumn 1993/spring 1994. Three other species, *Triticum aestivum* (cv. Maris Widgeon), *Zea mays* (cv. Leader) and Triticale (cv. Purdy) were included. Maris Widgeon, whilst not on the NIAB recommended cereal list, is a long-strawed variety grown extensively for thatch. It was chosen as a variety possibly with greater total yield potential. All other varieties were chosen because they scored highly for biomass production in the NIAB listings.

Winter cereals were sown on 3 November 1993 in 50 x 50 m blocks. Seed rates were 180, 160 and 160 kg/ha for wheat, rye and triticale respectively. Each block contained three replicates and within each replicate 5 N treatments were arranged randomly. At Rickwood, all plots received 50 kg N on 12 May 1994. Subsequently, on 14 May, additional units of 50, 100, 150 and 200 were applied, giving total N application treatments of 50, 100, 150, 200, 250 kg N. Chemical weed control was applied on 4 June (Impact excel @ 2l/ha, Corbal @ 0.75l/ha). Maize was drilled on 14 May 1993 at a rate of C. 180,000 seed/ha. N application treatments of 50, 100, 150, 200, 250 kg N were applied on 23 June. N rates applied to rye growing at Rothamsted were 0, 30, 60, 90 and 120 kg/ha.

Winter cereals were harvested over the period 16 August - 18 August. 1.25 x 5m strips were cut from the centre of each plot using an Agria mower scythe at Rickwood and manually at Rothamsted. Biomass yield was calculated from total fresh weight and fresh and dry weight sub-samples. Whole crop moisture content and harvest index (ratio of grain to total biomass harvested) were measured. Crop yields and dry matter content at harvest are presented in figures 6.5 and 6.6. Harvest indices were as follows 36-38% Maris Widgeon, 44-45% Amundo rye, 41-42% Purdy triticale. Maize was harvested on 21 October 1994.

There was a clear, significant response of Rye to N rate (least significant difference P>5%=2.69) at Rothamsted, but no significant response (at much higher rates) at Rickwood. Total biomass yield were much higher at Rothamsted than at Rickwood. Whilst the general pattern of yield for the other cereals was a slight increase with increasing N rate, Maris Widgeon exhibited a 2t/ha decline in yield between the highest and lowest rates. At Rickwood maize yields were generally greater than any other cereal, however, dry matter content was only 25%, compared with 65%+ for the other cereals. Dry matter content in both wheat and rye exceeded 70%. The yields in these cereals were greater than those experienced for any of the perennial species under study, and in the case of the winter cereals, a higher dry matter content.

Figure 6.6. Response of whole crop cereals (wheat, rye and triticale) to fertiliser nitrogen, 1994

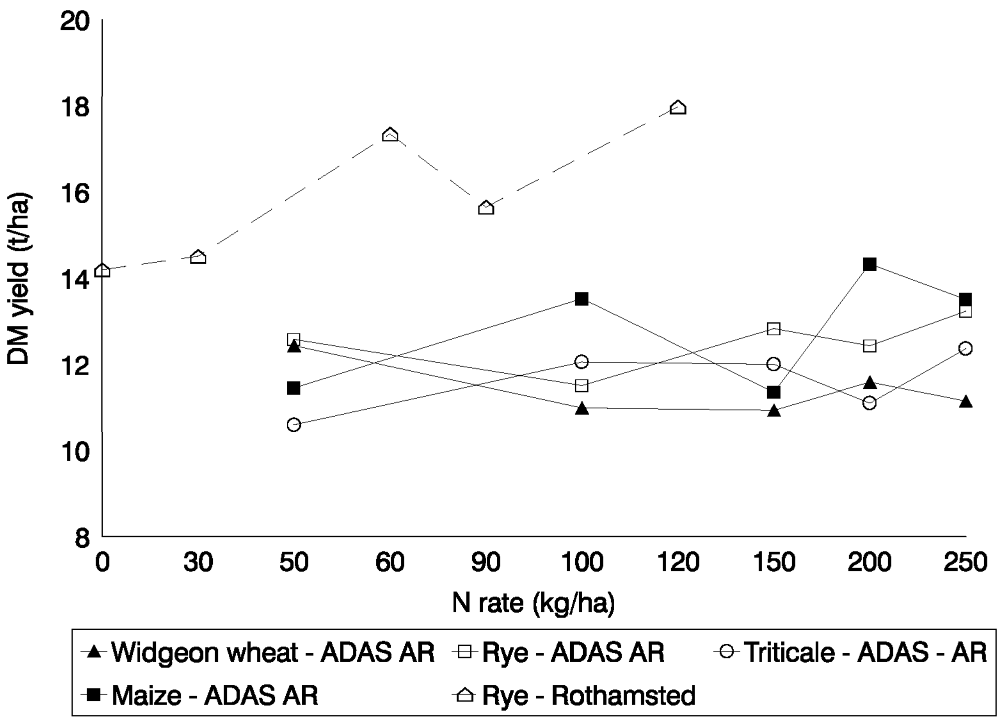


Figure 6.7. Dry matter content of whole crop cereals (wheat, rye and triticale) harvested in 1994

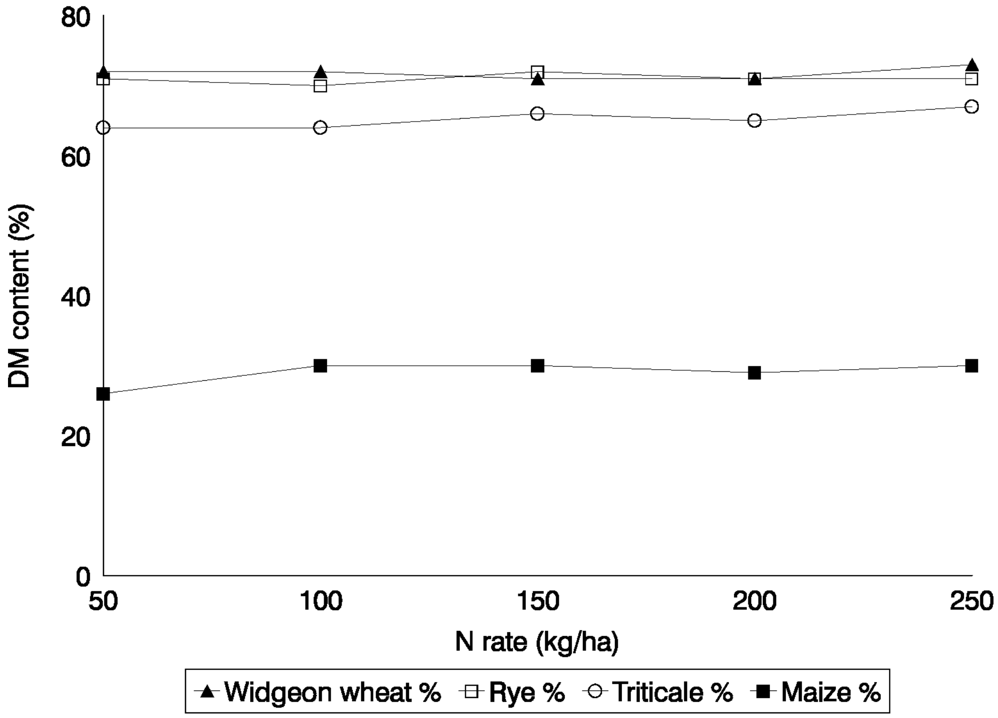
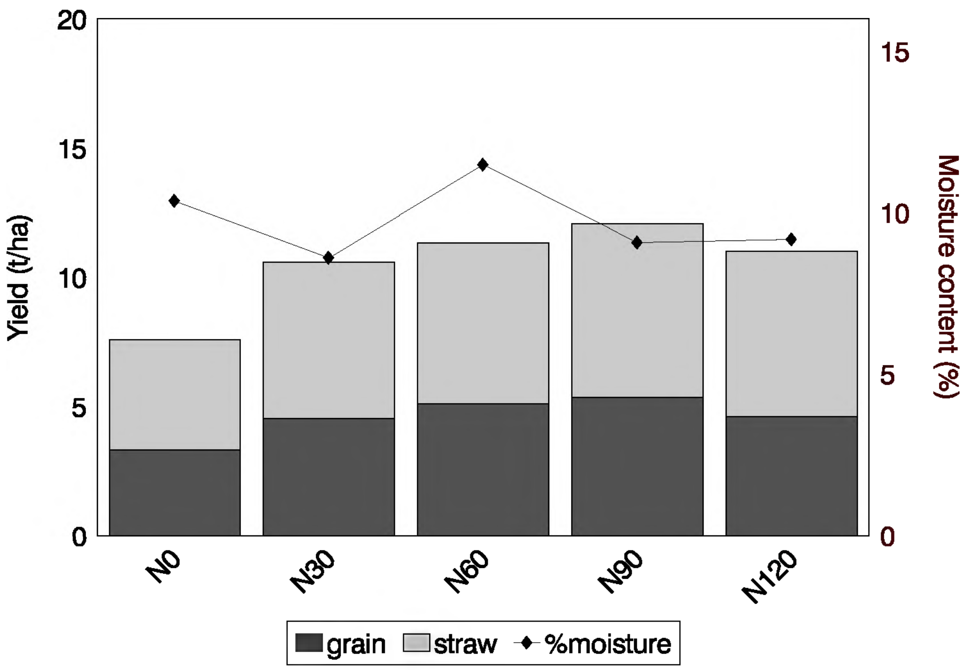


Figure 6.8 Yield and moisture content of rye at Rothamsted, 1995



During 1995 N response trials at Rickwood were discontinued, and three cereals simply compared with each other. Yields of rye at Rothamsted for 1995 are presented in Figure 6.8. Yields were significantly depressed due to the prolonged summer drought. Also, brown rust in rye at Rothamsted was not controlled effectively and this reduced yelds further.

6.5 Reed canary grass (*Phalaris arundinacea*)

A factorial experiment consisting of two varieties, five N application rates replicated four times in randomised blocks was established at Rickwood in 1994. A similar trial was established at Rothamsted comparing one variety, five N rates and replicated three times. At Rickwood, seed (20 kg/ha) was drilled (Oyjard drill) on 23 May 1994. Individual plots measured 4.1m x 10m. High germination rates were seen on all plots. However, summer growth was extremely slow, possibly due to moisture demand and weed growth was vigorous. Control of weeds at Rickwood was attempted with MCPA + MCPB @ 7.7 l/ha (27 June), bromoxynil + ioxynil @ 2.5 l/ha (16 July) and a tank mix of HBN (1l/ha) and CMPP + mecoprop (0.9l/ha) on 17 November 1994. The sward was not cut in 1994 due to slow establishment. Excellent growth was acheived at Rickwood during the first half of 1995. At Rothamsted poor emergence resulted in high variability between plants and the trial was re-sown in spring 1995.

Figure 6.9. Yield of a native Canadian ecotype of *Phalaris arundinacea* during 1995. Half the plots received their main cut on 13/6/95 with a second cut on 20/1/96, the remaining plots were harvested on 20/1/96 only. (SED =0.86)

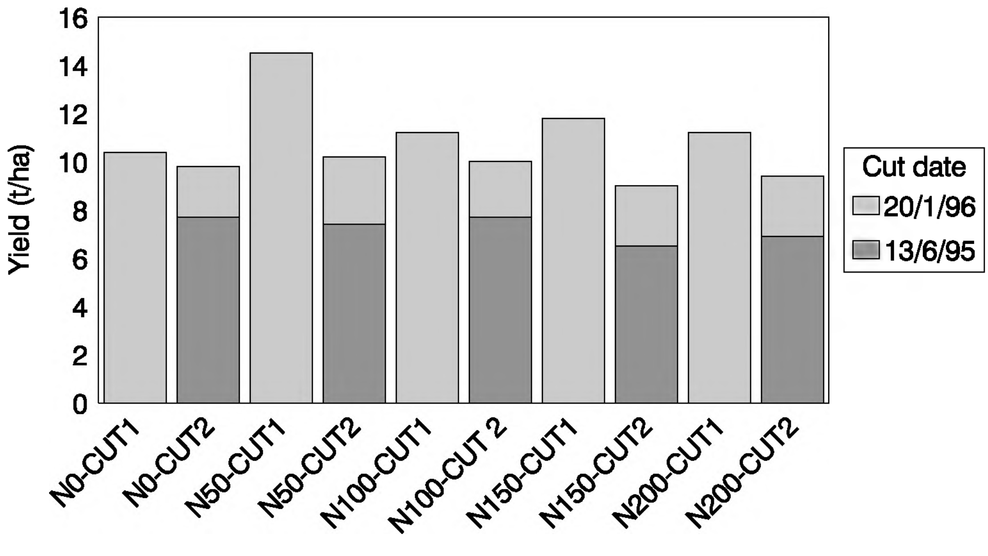
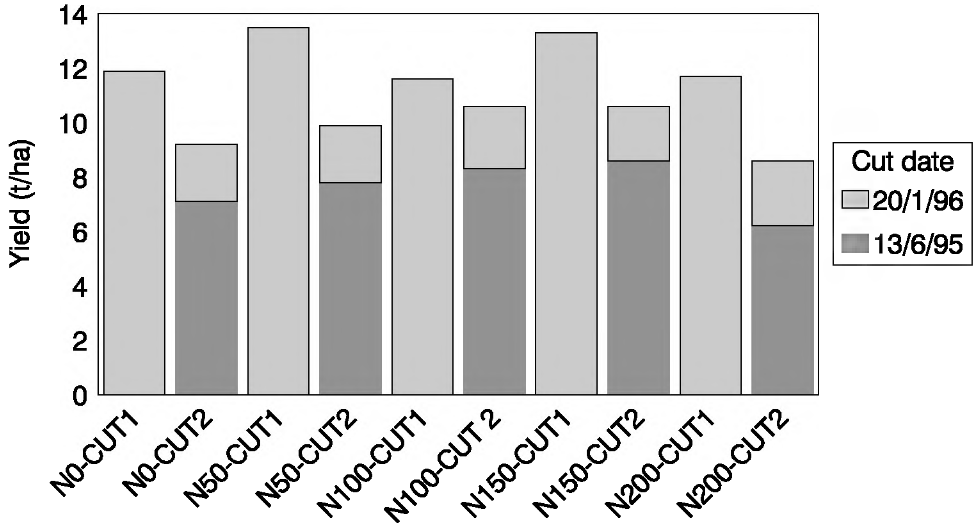


Figure 6.10 Yield of *Phalaris arundinacea* cv. Palaton during 1995. Half the plots received their main cut on 13/6/95 with an second cut on 20/1/96, the remaining plots were harvested on 20/1/96 only (SED=0.92)



The 1995/96 yields from the replicated screen of *Phalaris arundinacea* were extremely encouraging. Herbicidal control of weeds was not required, spring regrowth was early and rapid allowing an early cut and subsequent aftermath cut, as well as an end of season harvest. Figures 6.9 and 6.10 indicate that there was nothing to be gained by taking two cuts - yields were higher if the plants were left until the end of the season and moisture contents were lower. As with the other energy crops studied at Rickwood, there was no response to N fertiliser.

6.6. Cord grass *Spartina pectinata* -

Replicated experiments were laid down at Arthur Rickwood and Rothamsted consisting of five 5m x 5m plots replicated three times. However, particularly slow and uneven establishment prevented subsequent experimentation.

7. PLOT EVALUATION OF A RANGE OF POTENTIAL ENERGY CROPS: Un-replicated screening

Plots measuring 5m x 5m were established for each crop at the three participating centres. These crops have been identified as possibly having potential as biomass crops, and the specific objective of the study was to determine which species perform well enough to justify larger-scale study. Individual species have varied from site to site and from year to year, and have been treated appropriately to maximise productivity. N fertiliser application at Rothamsted has been a standard 60 kg/ha annually. For brevity, crop development is presented graphically for all species, but cultural treatment, results and discussion are presented for only the most successful species. Planting details and cultural treatment can be found in earlier, interim reports.

A comparison of crop heights, yield and moisture content at harvest for all crops are presented in figures 7.1 to 7.16. Notes on plot observations are presented for individual crops.

Field Trial Data at Rickwood and Rothamsted

The unreplicated screening indicated that only two species merit further study. All others have been found to be inappropriate, either because moisture content was too high at harvest (*Zea mays*, *Sorghum bicolor, Echinochloa frumentacea, Helianthus tuberosum*) or because of low biomass productivity (*Echinops ritro, Sorghum bicolor, Phragmites australis*). The species showing promise were *Phalaris arundinacea*, and *Spartina* spp. On the basis of annual harvests, these crops yielded at least equal amounts of biomass (on an annual basis) as the willow and poplar 'control' species. Of the crops growing on Rosewarne's contaminated soils, where all crops yielded very poorly, only *Arundo donax* and to a lesser extent *Miscanthus x giganteus* produced satisfactory yields.

Spartina pectinata

In 1993 harvestable dry matter yield of *Spartina pectinata* at Rothamsted was 2.8t ha^{-1} and 4.9 t ha^{-1} at Rickwood at an average moisture content of 48%. In 1994 crop yield increased to 7.8t ha^{-1} at Rothamsted and over 14 t ha^{-1} at Rickwood with moisture contents c. 50%. At Rothamsted improved yield is associated with an increase in stem density; 364% from 1993. Individual stem weights were closely similar in 1993/4 and 1994/5. In 1994, 38% of the dry matter was leaf and this had a moisture content of 17%. The stems had a moisture content of 42%. 1995/6 saw a further increase in yield. It is unclear whether the *Spartina* plants have achieved physiological maturity - there is certainly space between the plants for further rhizomatous shoot development. The major factor limiting the use of this species may be the current difficulties with establishment (and therefore cost).

Phalaris arundinacea

Yield and moisture content were seen to vary depending on the time of harvest. Early autumn harvesting resulted in high yields but has a high moisture content. Delaying harvest improved the dry matter content but reduced the yield. At both sites, a dense, even sward had developed by the second season. *Phalaris arundinacea* growth is initiated very early in the season, maximising radiation interception. This cold season growth makes it ideally suited to production in more northerly areas. The move towards replicated screening of phalaris (section 6.5) provided even more promising results for this species.

Miscanthus at Rosewarne
Miscanthus plantlets were slightly chlorotic on planting (15 June 1993) and the chlorosis persisted for at least four weeks after planting. This may have been due, in part, to the drought conditions shortly after planting and the poor condition of the plants before planting. During the first growing season there was a 99% successful establishment and the plants attained a mean height of 0.66 m. Plants began to senesce in November and the Miscanthus was harvested on 9 February 1994.

By June 1994, it became obvious that many plants had not survived the winter and further losses in spring resulted in a total loss of 35%. The growth habit of the Miscanthus was dictated by wind direction with the plant heights within the plot being very variable with the lowest in the least sheltered parts of the plot. In Year 2 a mean plant height of 1 m (max 1.8 m) was attained and the plot was harvested on 16 February. There was no large scale plant loss over the second winter.

1995 was an exceptionally hot, dry summer and this resulted in very poor growth of the Miscanthus in the third growing season. The plants attained a mean height of 1 m, At harvest, 40% of plants had over 20 stems and stem diameters were between 5 and 7 mm. Yields and moisture content of Miscanthus are shown in Fig 7.15 and 7.16. Senescence of the majority of the crop was achieved by December each year but some leaves remained green all winter. Flowers were observed on some Miscanthus plants in late summer, 1995. Owing to the poor growth of the Miscanthus crop, weed control was an ongoing problem although larger plots of non-experimental Miscanthus in the same field grew better and self mulched more efficiently. In comparison with Miscanthus growing at Rothamsted, Rickwood or Rosemaund, yields were extremely low.

Spartina at Rosewarne
Spartina plants were received in good condition as potted plants and when planted out on 15 June 1993 established quickly with no problems. During the first year growth of the Spartina outstripped the weed growth and by the end of the first year the plants were beginning to form a dense cover. By the third growing season measurement of individual plants and weed control became very difficult due to dense growth. Senescence started in October/November after flowering and seed production. Plant height only increased 20% between Year 1 and Year 2 and the crop was not noticeably taller in Year 3 (Fig 7.1) but was more bulky. The crop did not appear to be affected by wind damage and senesced early . Yields increased from 1.1 t/ha (61% moisture) in Year 1 to 1.6 t/ha (30% moisture) in Year 2 and 4.2 t/ha (27% moisture) in Year 3.

Arundo donax at Rosewarne
Arundo donax is a common native plant of the Southern Meditteranean which can grow up to 4 - 5 metres. It is used in Greece as a wind break at field boundaries and CRES has carried out field trials to assess the suitability as a biofuel. Rhizome pieces of approximatly 0.2 m were supplied by CRES and were planted out in April 1994 at Rosewarne at a plant spacing of 1 m. Shoots appeared quickly and there was 100% establishment. The plants grew well with little lodging and attained a height of 3 m in the second season (Fig 7.10). New shoots were continually being formed and did not die back in the winter. Although the climate at Rosewarne suited the growth of *Arundo donax* the crop did not senesce fully in either winter unlike the Greek trials which senesce in early autumn. (Christou, pers. comm.). Weed control with glyphosate in early spring was simple at the 1 m spacing. The plants had fewer stems than Miscanthus (2 - 15) in November 1995 and although the stems were much thicker

than those of Miscanthus wind effects were not noticeable. Aphids were noted on the crop in November 1995 but did not appear to damage the plants. A small amount of *Botrytis* and *Fusarium* was also noted. Average yield in 1996 was 5.6 t/ha at 57 % moisture with individual plants (5 samples) yielding from 0.2 t/ha to 11 t/ha. The low yield of some plants was due to animal damage.

Poplar & willow as control species

The willow plants were in good condition when planted and grew slowly but steadily throughout the three years. In the winter of Year 1 the plants were cut back to remove dead wood. The willow plants established easily but persistent animal damage killed two plants. Growth was slow but steady throughout the three years and by the Year 3 harvest the trees had attained heights of 2 - 3 m (Fig 6) with between 1 and 3 main branches. Yield was poor at 2.1 t/ha (53 % moisture). In Year 3 (late September) an infestation of willow bark aphid was noted on one plant. This was cleared by one application of 3%w/v heptanophos +0.75% permithrin (1:300). The leaves of the willow suffered persistent wind damage at this site. Poplar grew to about 1.5m tall in year 3 and yield was similar to willow. The main problem noted with poplar was wind damage to leaves.

Discussion of field trial data at Rosewarne

Comparison of data from the Rosewarne site with other more fertile and less exposed sites in the South of England gives the opportunity to assess the novel biofuel crops in a range of conditions.

The crops grown at Rosewarne, with the exception of *Arundo donax* grew slowly and had low yields compared to other sites. It should be borne in mind that different varieties suit different soil and climatic conditions. The following points should be noted:

- In both large and small plots of Miscanthus there is a very large effect due to prevailing wind, but in a small plot plants will not benefit from the sheltered microclimate generated within a large plot.
- The variety grown in the 5x5m plot (*Miscanthus x giganteus*) performed far better than any others on this site (7 t/ha at 50% moisture in 1996) with higher yields and earlier senescence.
- Rhizome cuttings established elsewhere in the field performed well with 100% successful establishment and no losses.

Willow and poplar variety trials in very exposed sites in the Rosewarne area have also reported vigorous growth for varieties such as *Salix alba* ‘Bowles hybrid’ and *Populus deltoides/trichocarpa* ‘Beupre’ and *Populus nigra* ‘Verrekin’ planted early in the growing season from hardwood cuttings.

Salix caprea and *Salix cinerea* are both native to Cornwall and grow on very exposed sites as well as more waterlogged environments although those growing on exposed sites exhibit dwarfism. It is probable that choice of variety is a very important factor for successful biomass production in Cornwall and promising new varieties should be screened not only for high yield but, in the case of Miscanthus and arundo, early senescence as the mild, wet climate of Cornwall is not compatible with early senescence of the plants supplied by ‘piccoplant’ as *Miscanthus x giganteus.*

Spartina appears to be well suited to the conditions at Rosewarne with easy establishment from transplanting, little wind damage, early senescence and a high dry matter content on harvest. Weed control of other grasses was found to be a problem in the established crop. However as Spartina is a C4 plant this should be controllable with C3-plant specific herbicides such as atrizine.

Figure 7.1 Crop height (cm) development of *Spartina pectinata* growing in un-replicated plots at Rothamsted, Rickwood and Rosewarne

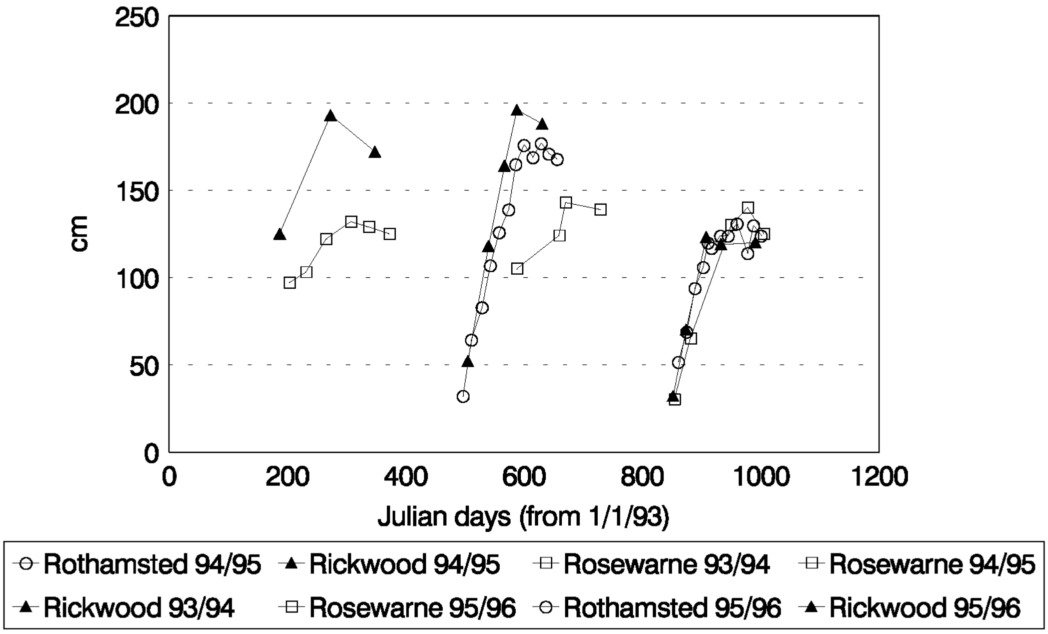


Figure 7.2 Crop height (cm) development of *Phalaris arundinacea* growing in un-replicated plots at Rothamsted and Rickwood

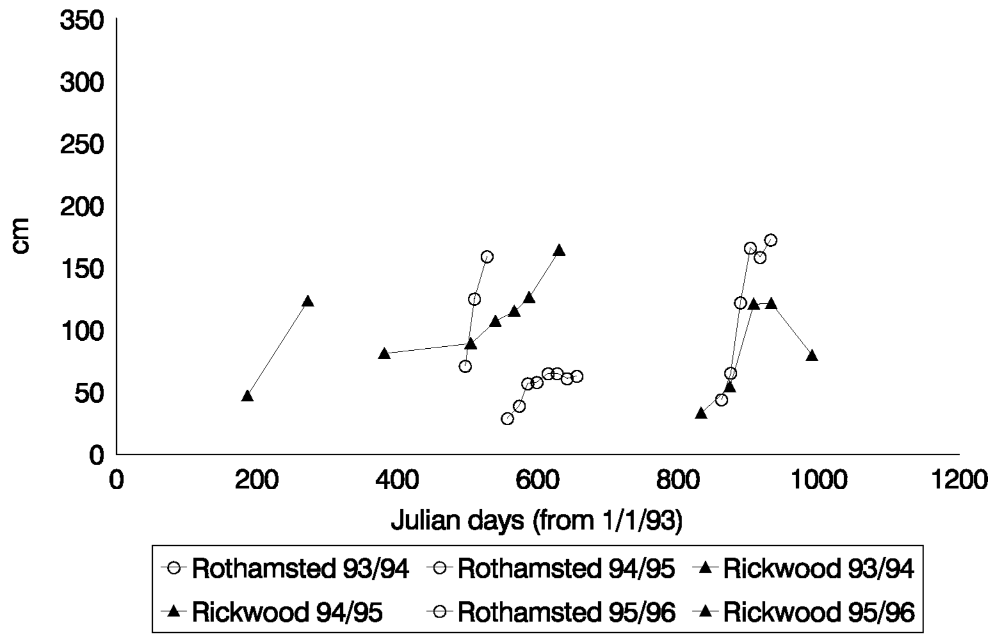


Figure 7.3 Crop height (cm) development of *Salix repens* growing in un-replicated plots at Rothamsted, Rickwood and Rosewarne

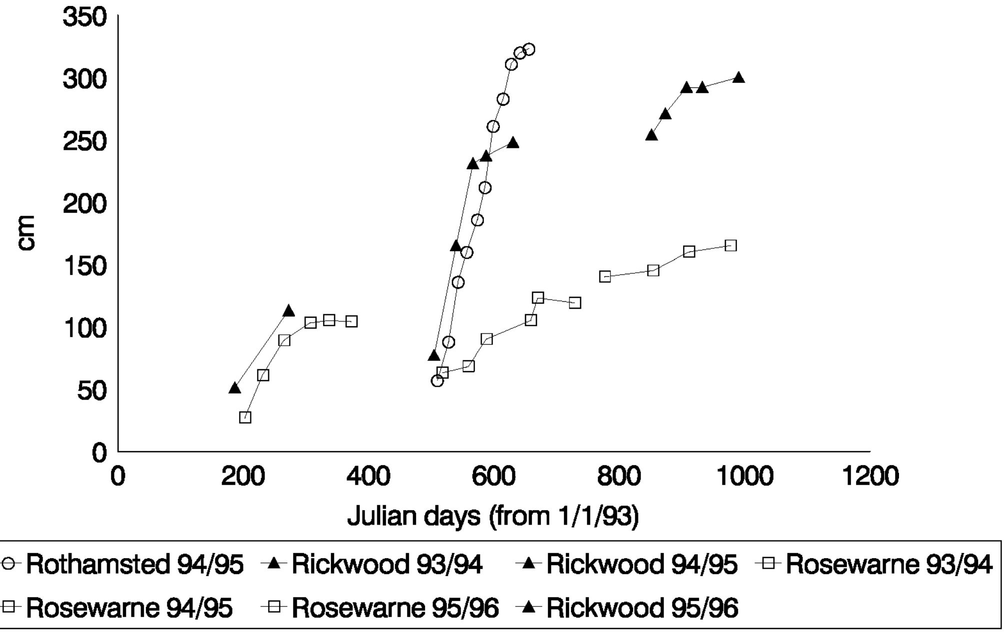


Figure 7.4 Crop height (cm) development for *Populus nigra* growing in un-replicated plots at Rothamsted, Rickwood and Rosewarne

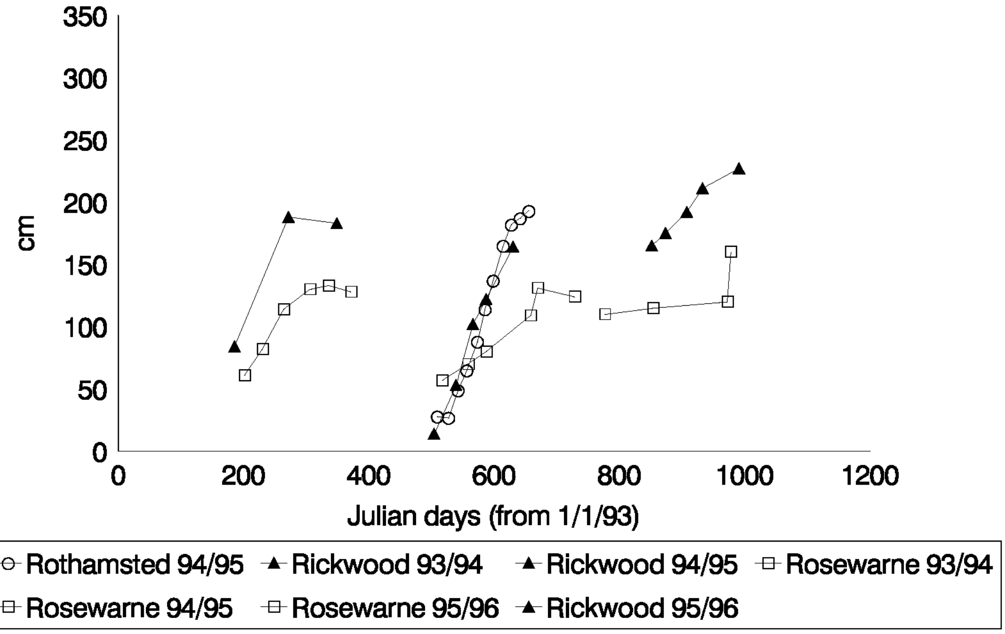


Figure 7.5 Crop height development of *Helianthus tuberosum* growing in un-replicated plots at Rothamsted and Rickwood

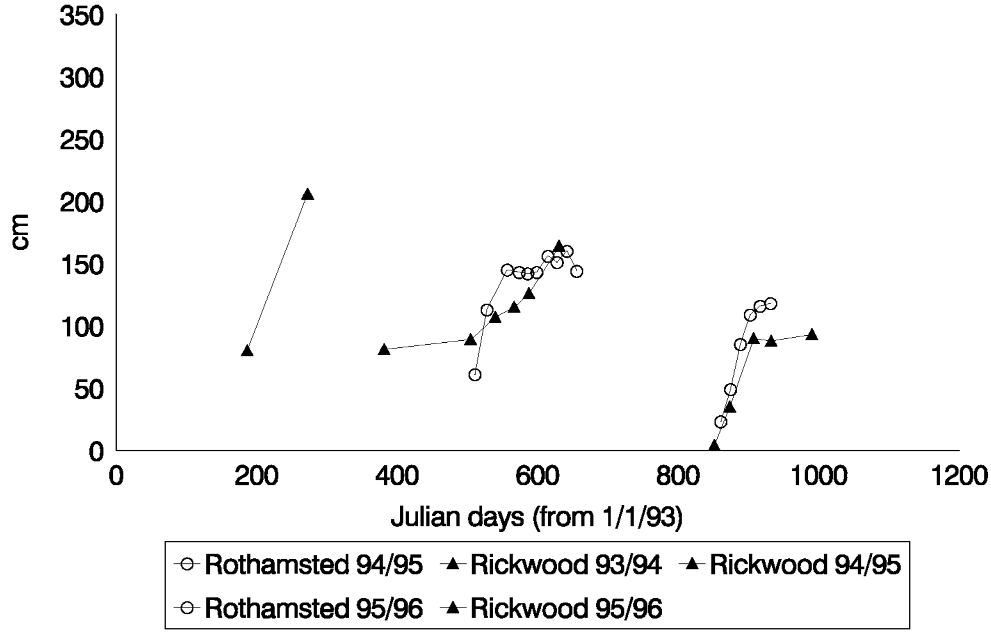


Figure 7.6 Crop height develpment of *Echinops ritro* growing in un-replicated plots at Rothamsted and Rickwood

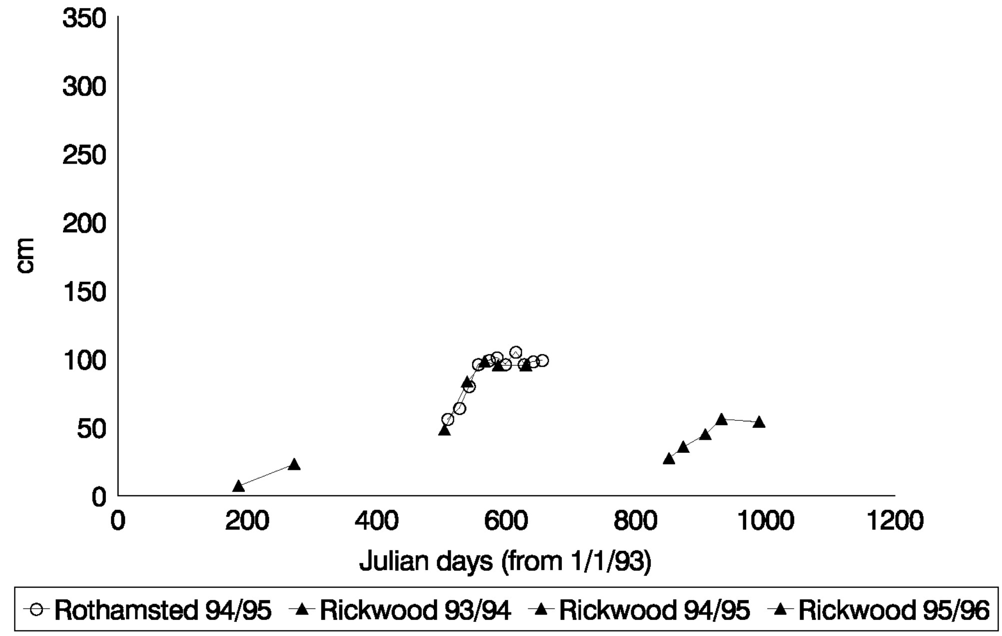


Figure 7.7 Crop height (cm) development of *Spartina cynosuroides* at Rothamsted

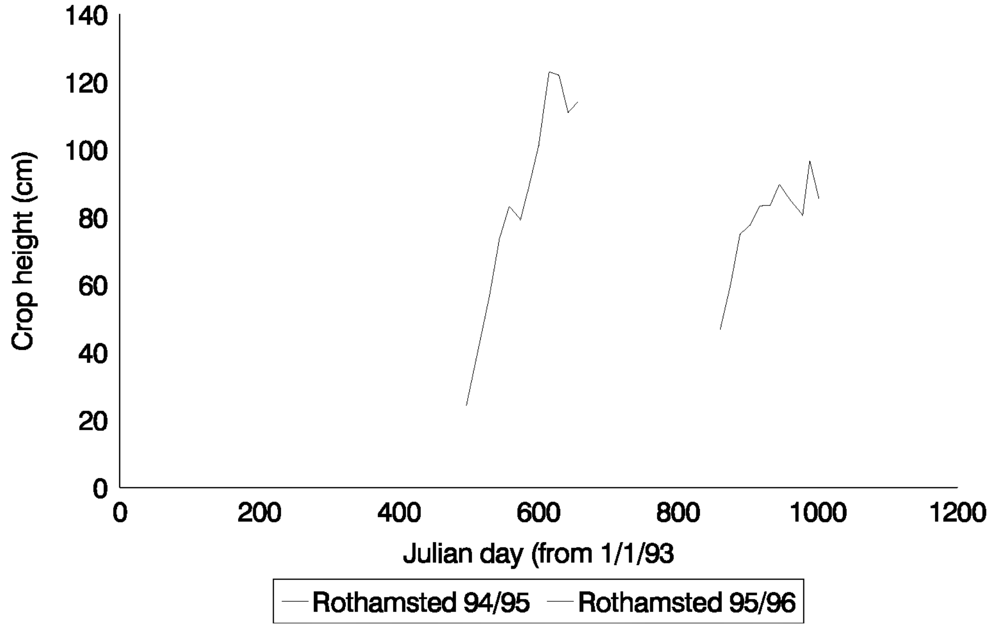


Figure 7.8. Survival of *Miscanthus x giganteus* at Rosewarne throughout the duration of the project.

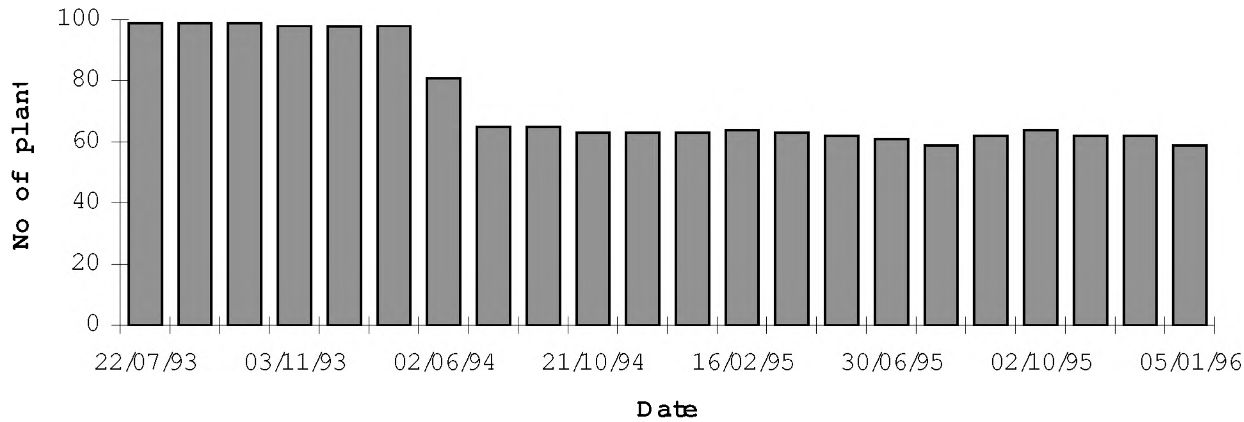


Figure 7.9 Crop height of *Miscanthus x giganteus* at Rosewarne throughout the duration of the experiment

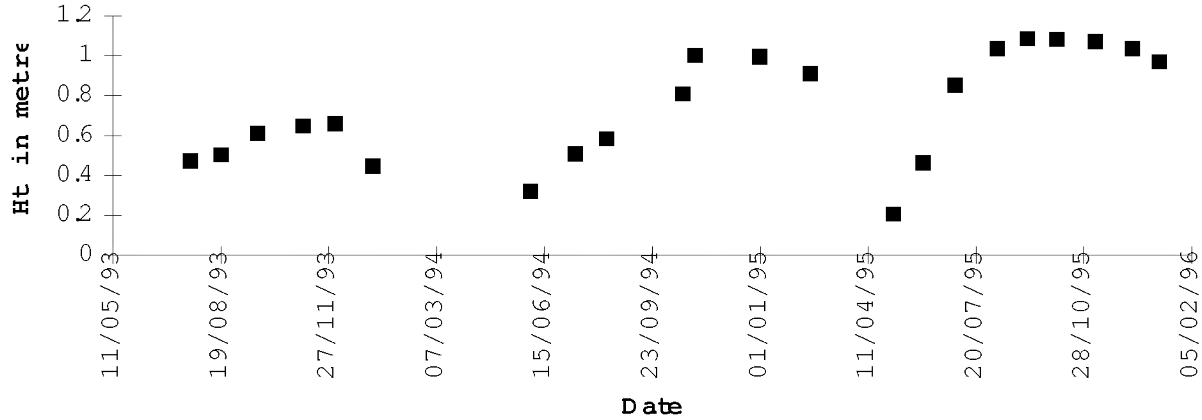


Figure 7.10. Crop height of *Arundo donax* at Rosewarne throughout the duration of the experiment.

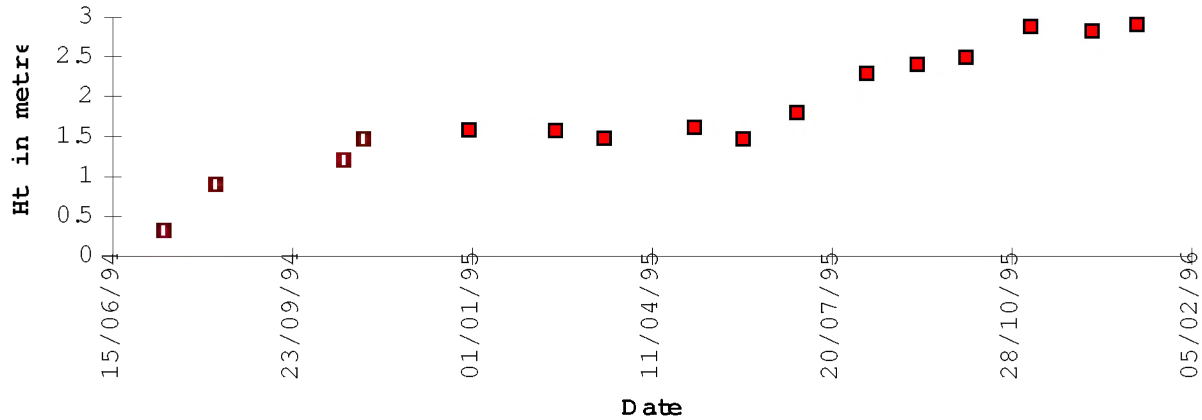


Figure 7.11 Biomass yield (t ha^{-1}) at harvest for crop species in the unreplicated plots grown at Rickwood.

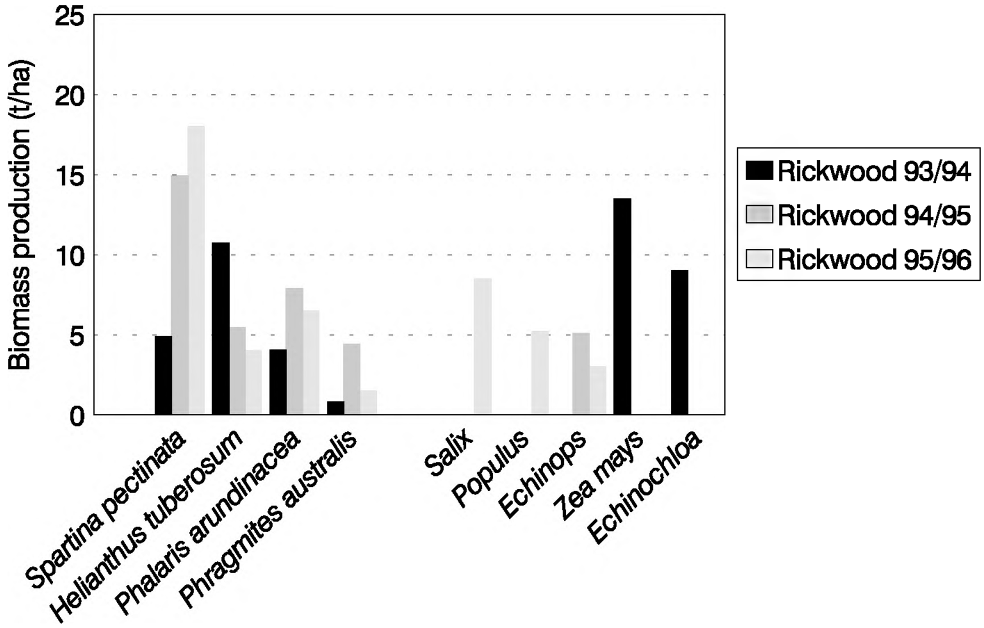


Figure 7.12 Moisture content (%) at harvest for crop species in the unreplicated plots grown at Rickwood.

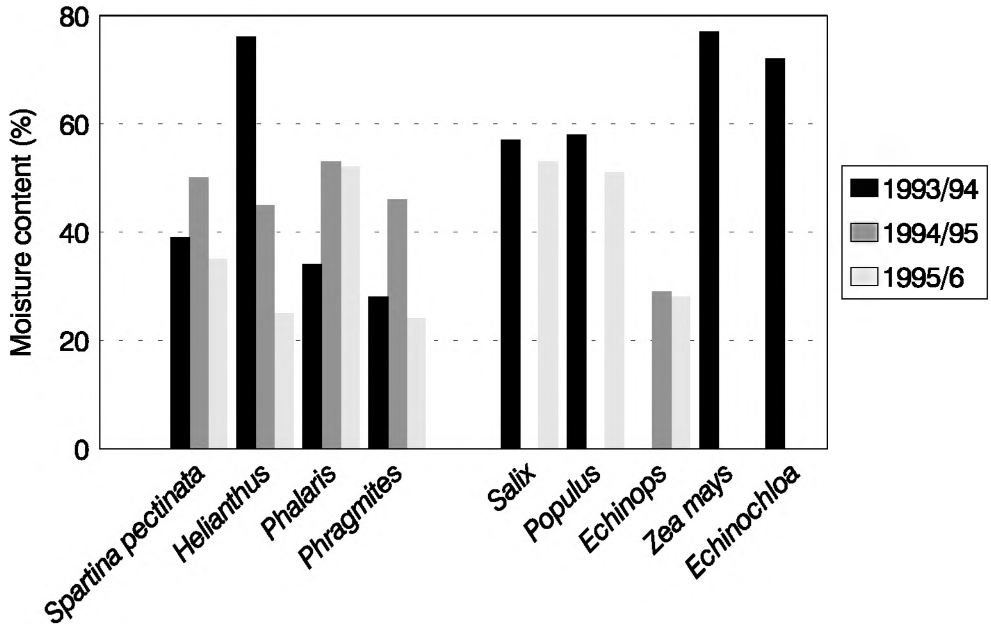


Figure 7.13 Biomass yield (t ha^{-1}) at harvest for crop species in the unreplicated plots grown at Rothamsted

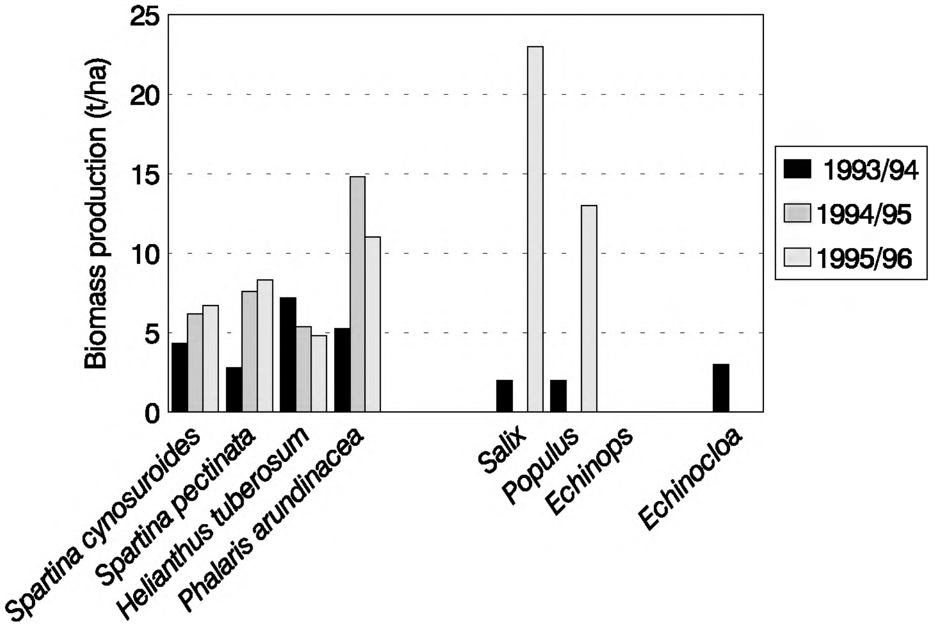


Figure 7.14 Moisture content (%) at harvest for crop species in the unreplicated plots grown at Rothamsted.

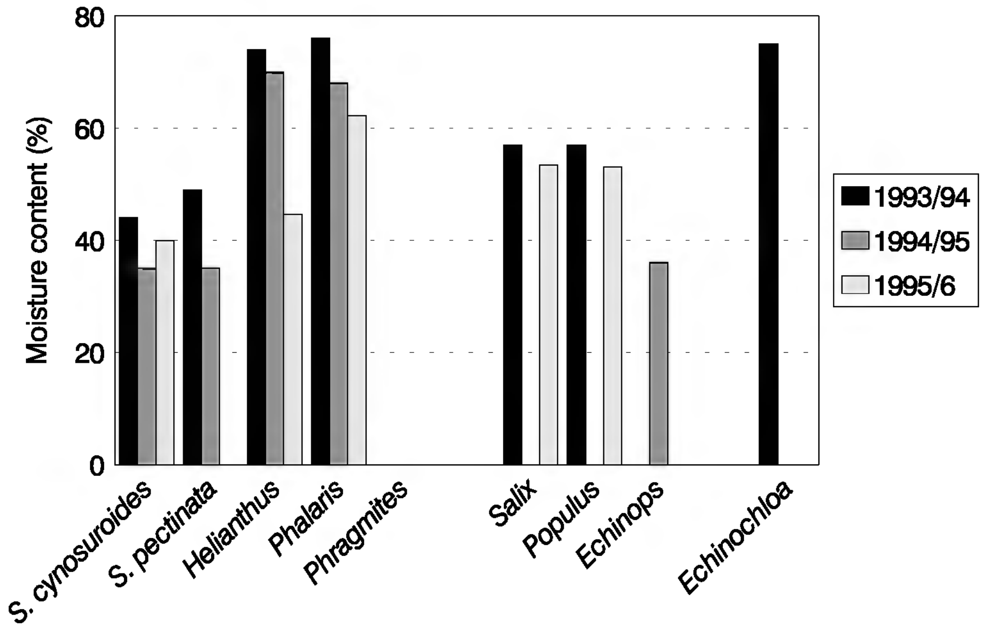


Figure 7.15 Biomass yield (t ha^{-1}) at harvest for crop species in the unreplicated plots grown at Rosewarne.

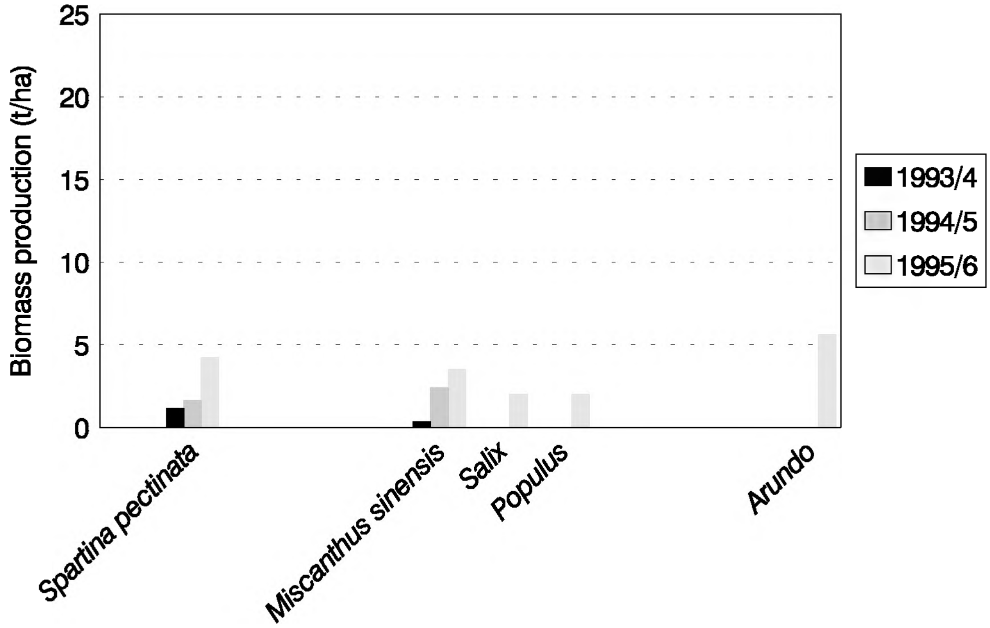
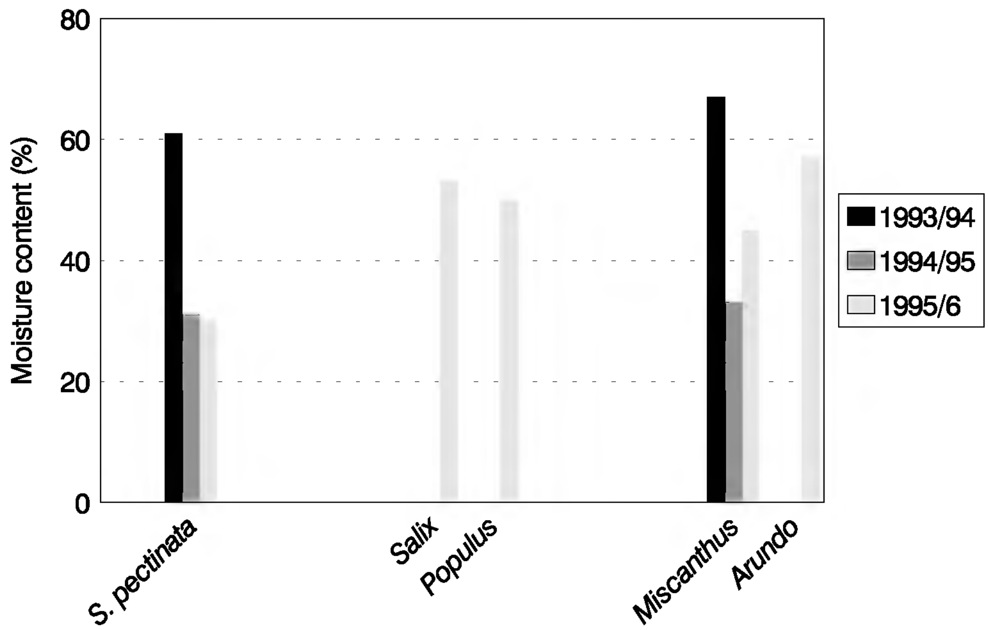


Figure 7.16 Moisture content (%) at harvest for crop species in the unreplicated plots grown at Rosewarne.



8. ENVIRONMENTAL IMPACT

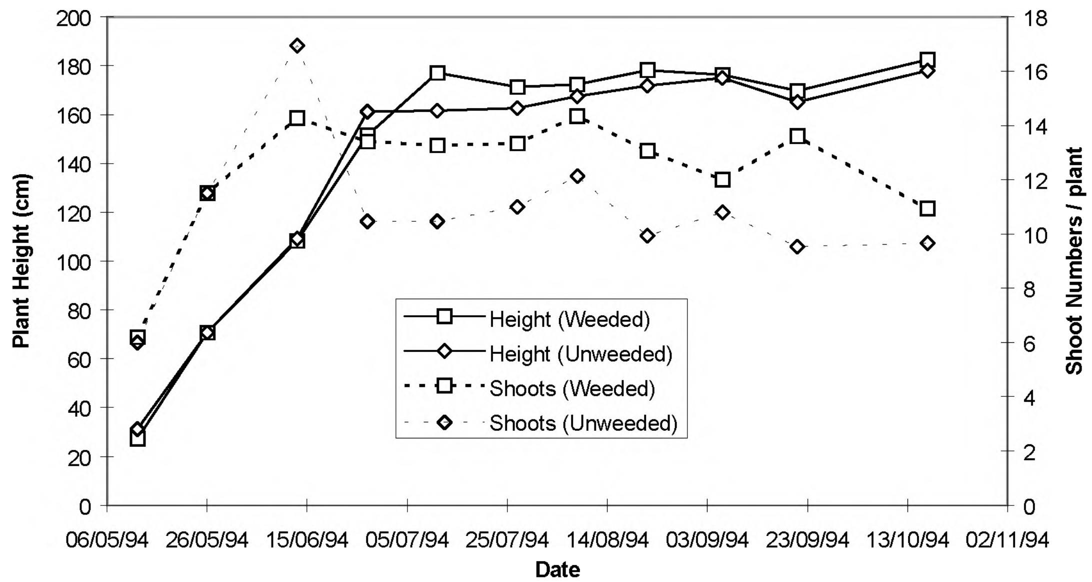
8.1 Weed Control

All crops included in the replicated and unreplicated studies have shown the need for weed control during the establishment phase. C4 grasses are slow to emerge and develop and become subject to competitive pressures from indigenous weeds. It was particularly noted at Rickwood and Rothamsted that in the first year of growth *Phalaris* and *Panicum* were surpressed by weeds and some young plants killed. In the second year a residual spray helped to check weeds in the early spring and once established *Phalaris* became very competitive and did not require further herbicides. Some species of *Panicum* formed a dense canopy and effectively controlled the weed understory.

Herbicide control of weeds within the Miscanthus plots at Rickwood was achieved relatively easily with a wide range of C3-specific and dicot-specific chemicals. At all sites the fully developed canopy of *Miscanthus* helped supress weeds within the plot but common to all plots, the edges became weedy. At Rothamsted an observational study of *M. sacchariflorus* started in 1994. This has shown that shoot number and plant height were improved by removal of weeds during the period shoots were emerging and the advantage gained continued throughout the season. (fig. 8.1). Yield was approximately 40% heavier where weeds were controlled. These observations were also seen in the 1995/6 season.

The residual behaviour of pesticides in soils containing perennial biomass species requires investigation, particularly when these species are close to water courses.

Figure 8.1 *Miscanthus sacchariflorus* shoot numbers and plant height on areas that were weeded or left unweeded during early growth 1994.



Herbicidal weed control becomes increasingly unnecessary as the canopy develops.
Weed species present in the canopy of mature *M. x giganteus* are presented in Table 8.1.

Table 8.1 Weed species found in the *Miscanthus x giganteus* site at Arthur Rickwood (July 1995).

Species (common name)	Life- cycle
Aethusa cynapium (Fool's parsley)	annual
Anchusa arvensis (bugloss)	annual
Fallopia convolvulus (black bindweed)	annual
Capsella bursa-pastoris (shepherd's purse)	annual
Chenopodium album (fat-hen)	annual
Cirsium arvense (creeping thistle)	perennial
Cirsium vulgare (spear thistle)	perennial
Epilobium spp. (willowherbs)	
Galeopsis tetrahit (hemp nettle)	annual
Galium aparine (cleavers)	annual
Matricaria spp. (mayweeds)	annual
Polygonum aviculare (knotgrass)	annual
Polygonum persicaria (redshank)	annual
Sonchus arvensis (perennial sowthistle)	
Sonchus oleraceus (annual sowthistle)	perennial
Senecio vulgaris (groundsel)	annual
Stellaria media (chickweed)	annual
Urtica urens (small nettle)	annual
Viola arvensis (field pansy)	annual

8.11 Short and Long-Term Ecological Considerations

The temporal changes in a weed community may be very different within a perennial crop, and may have important implications for future weed control strategies. An examination of the phenology and ecological strategies of different weed species may provide some insight into how these changes may occur, and what these changes might be.

Grime *et al.* (1988)[1] have defined plant species by their ecological strategies, a strategy being 'a grouping of similar or analogous genetic characteristics which recurs widely among species or populations and causes them to exhibit similarities in ecology'. In addition the primary strategy 'involves more fundamental activities of the organism (resource capture, growth and reproduction) and recurs widely both in animals and plants'. Most agricultural weed species are described on the basis of their species phenologies, as 'ruderals' (see Table 8.2). These species are commonly associated with disturbed fertile sites - exhibiting high relative growth rates and a large investment in reproduction and the production of long-term seed banks. Those ruderals in agricultural sites will typically be those which, as annuals, can respond to seasonal disturbances (i.e. ploughing). In long-term Miscanthus plantations, however, the 'stale seedbed' may seriously reduce the options for species regeneration as there will be a lack of soil disturbance through successive years. In addition, as light is restricted from the base of the canopy for the entire period June-March, only those species with spring-germinating seed stand a realistic chance of survival. Under these new conditions it is possible that we shall see a new weed fauna develop, consisting of perennial competitive species, spring-germinating ruderal species and also 'stress tolerators' such as species which

[1] Grime, J. P; Hodgson, J. G., Hunt, R (1988) *Comparative Plant Ecology*. London: Unwin Hyman.

are adapted to low light conditions, or opportunistic species which can take advantage of 'gaps' within the canopy. As an example, the species listed in Table 8.1 were noted on 12 July 1995 within a mature Miscanthus sward growing on an organic (peat) soil with an inherently high weed burden (1400 plants/m²). These provide the baseline for an assessment of species diversity and frequency change within a Miscanthus canopy. Although these species were found in a plantation in its third year of establishment (i.e. mature), large-scale destructive sampling throughout the lifetime of the sward has given rise to much soil disturbance and areas where much more light penetrates to the base of the canopy. Furthermore, this experiment has allowed us to assess the effect that Miscanthus crop density has on weed diversity, frequency and development. *Miscanthus x giganteus* were established at 40,000 and 17,777 plants/ha. Whilst species diversity was similar at both densities, species abundance was much higher at the wide density where canopy closure occurred later, and consequently weeds had a longer time for development. At this spacing these weeds were also at a more advanced phenological stage, many flowering in June, whereas at the high density the plants were etiolated and still vegetative.

Table 8.2. Weed species, their general and reproductive strategies (after Grime *et al.*, 1988) and life-cycle, associated with *Miscanthus sinensis* 'Giganteus' growing at two densities in the Cambridgeshire Fens.

Species (common name[1])	General Strategy[2]	Reproductive. startegy[3]	Life- cycle
Aethusa cynapium (Fool's parsley)	R	S,B_S	annual
Anchusa arvensis (bugloss)	R/CR	B_S	annual
Fallopia convolvulus (black bindweed)	R?	B_S?	annual
Capsella bursa-pastoris (shepherd's purse)	R	B_S (all year)	annual
Chenopodium album (fat-hen)	R/CR	B_S (spring)	annual
Cirsium arvense (creeping thistle)	C	V,W,B_S	perennial
Cirsium vulgare (spear thistle)	CR	W,B_S	perennial
Epilobium spp. (willowherbs)	--[4]	--	
Galeopsis tetrahit (hemp nettle)	R/CR	B_S (spring)	annual
Galium aparine (cleavers)	CR	S (spring/autumn)	annual
Matricaria spp. (mayweeds)	--	--	annual
Polygonum aviculare (knotgrass)	R	B_S (spring)	annual
Polygonum persicaria (redshank)	R	B_S (spring)	annual
Sonchus arvensis (perennial sowthistle)	R/CR		
Sonchus oleraceus (annual sowthistle)	R/CR	W,B_S	perennial
Senecio vulgaris (groundsel)	R	W,B_S (spring)	annual
Stellaria media (chickweed)	R	B_S, V spring/ autumn	annual
Urtica urens (small nettle)	R/CR	B_S (spring)	annual
Viola arvensis (field pansy)	R	B_S	annual

[1]Species names according to Stace (1992).
[2]General ecological strategy, after Grime *et al.* (1988); R = ruderal, C = competitor, CR = competitive ruderal.
[3]Reproductive strategy, after Grime *et al.* (1988); V= vegetative expansion, S = seasonal regeneration, B_S = persistent seed bank, W = widely dispersed seed.
[4]Data unavailable.

8.2 Invertebrate Communities Within Miscanthus

8.2.1 Larval Associations

Larvae of the Noctuid moth *Mesapamea secalis* L. were found to be feeding within a small but significant proportion of the plants at Arthur Rickwood during April and May of both 1994 and 1995. Larvae fed on the developing leaves within the leaf sheath. Affected stems exhibited a characteristic constriction, above which tissue became rapidly necrotic. Affected stems did not develop. However, no individual plant was killed by these larvae. The larvae of this insect usually associate with other members of the graminae, and the larvae were showing host switching.

8.2.2 Earthworms under Miscanthus

Methods

An assessment of earthworm populations was made at Rothamsted in 1993 and 1995. Sampling was by expulsion using a solution containing formaldehyde over an area of $1m^2$ (Raw 1959)[1] . The central $0.25m^2$ of the treated soil was dug out to 30cm and the soil hand sorted over a sieve. On the second sampling occasion it was not possible to use a $1m^2$ quadrat within the crop. Instead a cylindrical ring 31.5cm diameter was located between the clumps of rhizome and the irritant applied to the soil confined by the ring. The soil was subsequently dug to 30cm and sorted. The first sampling was made in October 1993 and the second in December 1995.

External characteristics of the earthworms were used to identify species. Individual species were not identified and earthworms were grouped according to the connection of the peristomium and prostomium. Maturity was recognised by the presence of the clitellum.

Between October 1993 and December 1995 the total number of earthworms recovered increased by 17%. The number of tanylobus and epilobus types increased by 50.6% and 11.3% respectively. The number of immature tanylobus types increased by 70.6% and epilobus types by 33.7%. No mature tanylobus types were found and the number of mature epilobus types have declined by 48.8%.

Worms with the tanylobus characteristics are of the species lumbricus. The burrows of some of the lumbricus can be very deep and therefore they are important species for the mixing of organic matter and nutrients between the topsoil and subsoil. Burrows can also improve aeration of the soil.

Epilobus types can be both burrowing and soil living and inhabit shallower depths of the soil. This means that their populations are more likely to be affected by tillage and in the absence of tillage populations could be expected to increase, although there was only a 26 month interval between samplings the increase in the number of earthworms of both characteristic types suggests that the soil environment in the Miscanthus is not adversely affecting the earthworm population. The second sampling took place after a very dry summer, sampling had been attempted in October 1995 but no worms had been found, probably because the soil conditions were very dry and this is known to influence worm activity, and mortality. The

[1] Raw, F. 1959 Estimating earthworm populations by using formalin. Nature, London, 184, 1661

length of the immature stage of growth is affected by dry soil conditions and this may have influenced the proportion of immature to mature worms that were found.

Earthworms are very sensitive to small differences in environment. Localised compaction, or wetness can affect populations therefore quite large differences in number between samples can be normal.

Problems of sampling within the crop without destroying plants through digging means that the sampling may underestimate populations because any earthworms below the roots and rhizomes of the plant may not be affected by the irritant solution.

Table 8.3. Earthworm populations found in Miscanthus 1993 and 1995

1993

Sample No	Total Worms	Tanylobus		Epilobus	
		Mature	Immature	Mature	Immature
1	45	1	9	7	28
2	50	-	5	15	30
3	1	-	-	1	-
4	13	1	1	2	9
Total	109	2	15	25	67
average m^{-2}	27.25	0.5	3.75	6.25	16.75

1995

Sample No	Total Worms	Tanylobus		Epilobus	
		Mature	Immature	Mature	Immature
2/3	1	-	-	1	-
3/4	2	-	1	1	-
4/5	10	-	1	3	6
8/9	6	-	-	5	1
Total	19	-	2	10	7
average m^{-2}	60.8	-	6.4	3.2	22.4
% Change 1993-1995	223.4	-	170 6	57.2	133.7

8.2.3 Pitfall trap survey of beetles and spiders.

Results of autumn survey at Rothamsted,1995/6 are presented in Table 8.4 and 8.5.

In both rye and Miscanthus there were more beetles than spiders found. Traps were not placed on the rye plots in September because the crop had not been sown but in October the number captured was very similar to the total captured in Miscanthus in September and October.

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There were more beetles found in rye than Miscanthus but there was a greater species diversity in Miscanthus. On both experiments early trapping generally captured greater numbers of beetles indicating that during the period populations were not increasing.

The number of spiders was 3 times greater in Miscanthus than in rye and there were more species found. Captures were more evenly spread over the assessment period.

Web spinning species like Erigone were absent on the Miscanthus but there were greater numbers of Lycosa species which are hunting spiders. Total populations of both spiders and beetles are typical for the autumn in arable land.

Table 8.4 Results of beetle survey autumn 1995

Species *Miscanthus*	Sept	Oct	Nov	Dec	Total
Amara aenea	0	1	0	0	1
Amara familiaris	0	1	0	0	1
Amara plebja	2	1	0	0	3
Bembidion guttula	2	0	0	0	2
Harpalus rufipes	29	0	0	0	29
Nebria brevicollis	0	0	0	0	0
Nebria salina	0	0	0	0	0
Philonthus spp.	2	0	0	0	2
Pterostichus madidas	34	9	0	0	34
Pterostichus melanarius	4	0	0	0	4
Quedius spp.	1	0	0	0	1
Staphylinus olens	3	3	0	0	6
Trechus quadristriatus	11	1	0	0	12
Xantholinus linearis	0	0	0	0	0
Carabid larva	0	0	1	1	2
Staphylinus larva	0	0	1	1	2
Total	88	16	2	2	108

Rye	Oct	Nov	Dec	Total
Amara aenea	0	0	0	0
Amara familiaris	0	0	0	0
Amara plebja	0	0	0	0
Bembidion guttula	0	0	0	0
Harpalus rufipes	0	0	0	0
Nebria brevicollis	54	0	0	54
Nebria salina	0	9	9	18
Philonthus spp.	0	0	0	0
Pterostichus madidas	37	10	0	47
Pterostichus melanarius	11	0	0	11
Quedius spp.	0	0	0	0
Staphylinus olens	3	1	0	4
Trechus quadristriatus	1	0	0	1
Xantholinus linearis	2	1	1	4
Carabid larva	0	2	3	5
Staphylinus larva	0	0	2	2
Total	108	23	15	146

Table 8.5 Results of spider survey autumn 1995

Species

Miscanthus

	Sept	Oct	Nov	Dec	Jan	Total
Aleopecosa pulverentata	0	2	2	0	0	4
Bathyphantes gracillis	1	0	1	0	0	2
Centromerita bicolor	0	0	2	3	1	6
Centromerus sylvaticus	0	0	0	4	3	7
Cicurina circur	0	1	0	0	0	1
Erigone atra	0	0	0	0	0	0
Erigone dentipalpis	0	0	0	0	0	0
Lepthyphantes tenuis	1	2	0	0	0	3
Lycosa agricola	0	3	0	1	0	4
Lycosa arenicola	0	3	0	0	0	3
Lycosa monticola	0	1	0	0	0	1
Lycosa Prativaga	1	0	0	0	0	1
Walckenaeria accuminata	0	0	0	1	1	2
Immature Lycosa	3	0	0	0	0	3
Immature lyniphidae	0	0	0	1	0	1
Total	6	12	5	10	5	33

Rye

	Oct	Nov	Dec	Jan	Total
Aleopecosa pulverentata	0	0	0	0	0
Bathyphantes gracillis	0	0	0	0	0
Centromerita bicolor	0	1	1	3	5
Centromerus sylvaticus	0	0	0	0	0
Cicurina circur	0	0	1	0	1
Erigone atra	0	0	0	0	0
Erigone dentipalpis	0	0	0	2	2
Lepthyphantes tenuis	0	0	2	0	2
Lycosa agricola	0	0	0	0	0
Lycosa arenicola	0	2	0	0	2
Lycosa monticola	0	0	0	0	0
Lycosa Prativaga	0	0	0	0	0
Walckenaeria accuminata	0	0	0	0	0
Immature Lycosa	0	0	0	0	0
Immature lyniphidae	0	0	0	0	0
Total	0	3	4	5	12

8.4 Wind and micro-climate effects

One of the most important envionmental impacts of an energy crop which has the potential to exceed 3m in height is its effect on local wind speeds and air circulation. At Rickwood relatively crude estimates of local windspeed modification was made by placing anemometers above the crop canopy, within the crop canopy, and on both the windward and leaward side of the crops.

Results for windspeed in 1996 are presented in figures 8.2 and 8.3. Differences in temperature within the soil and the canopy (measured in 1995) are presented in figures 8.4 and 8.5.

Figure 8.2. Percentage depression of wind speed caused by a Miscanthus crop over the period 12 - 21 January 1996.

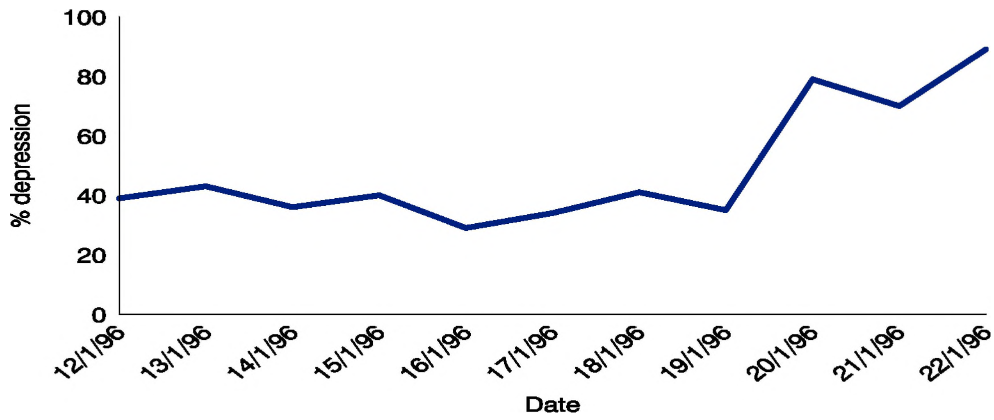

Figure 8.3 Percentage depression of wind speed caused by a Miscanthus crop over the period 20 - 27 November 1995.

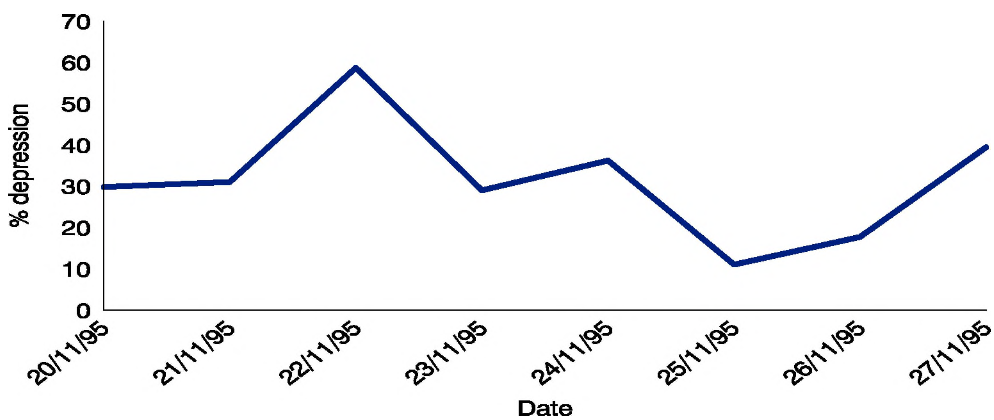

Figure 8.4. Soil surface temperatures within two Miscanthus plantation densities (0.75m and 0.5m spacing). Measurements taken over the period 17-20 May 1995.

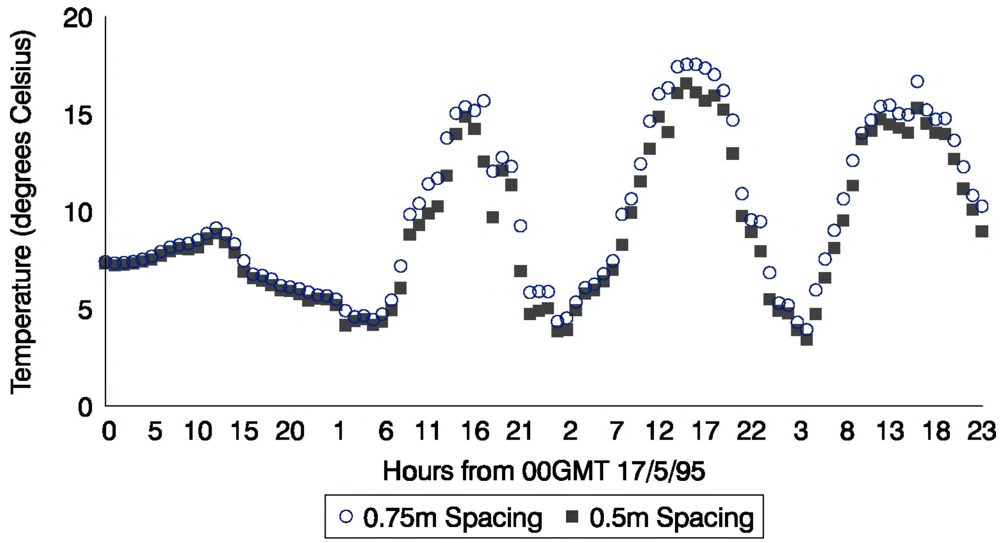

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Figure 8.5 Soil surface and 10cm deep temperatures (°C) within two Miscanthus plantation densities (0.75m and 0.5m spacing). Measurements taken over the period 17-20 June 1995.

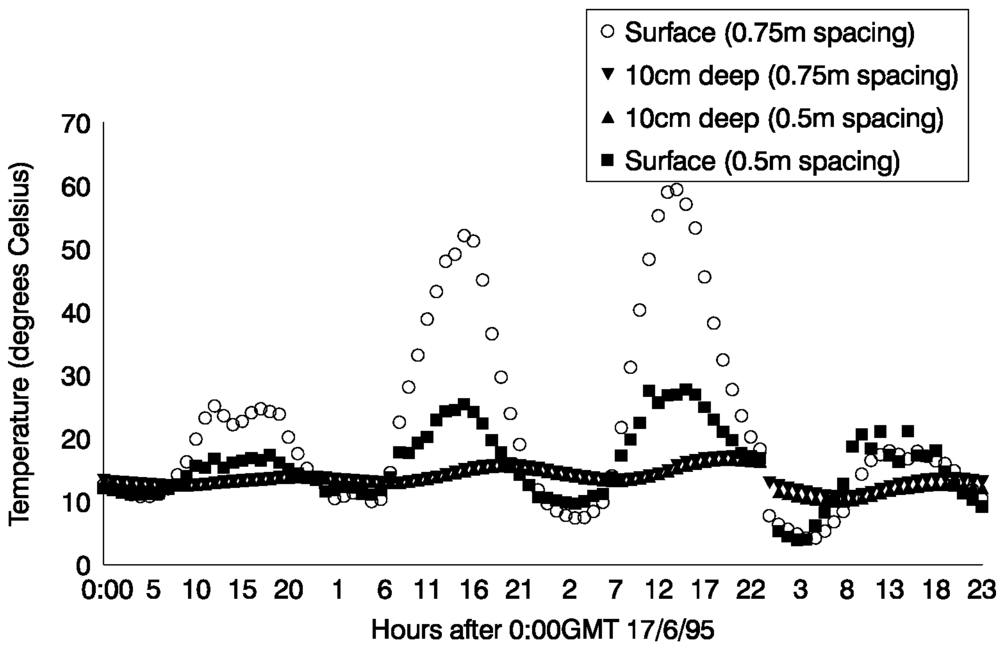


Figure 8.6 Soil surface and 10cm deep temperatures (°C) within two Miscanthus plantation densities (0.75m and 0.5m spacing). Measurements taken over the period 17-20 April 1995.

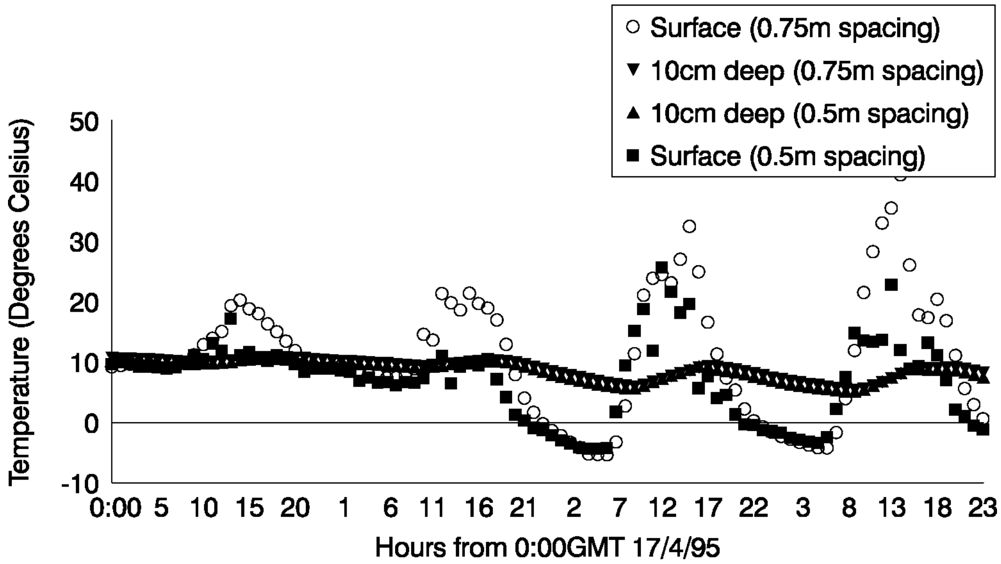
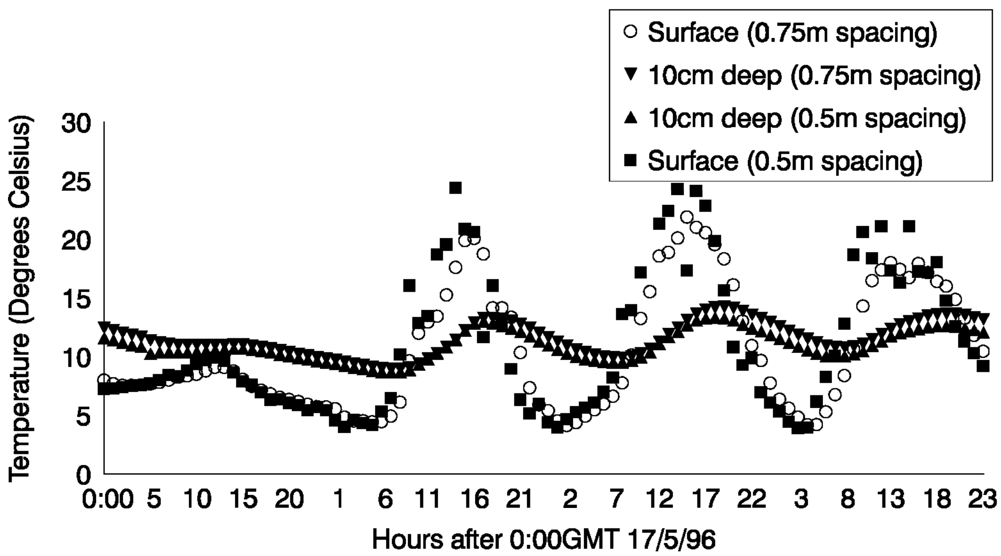


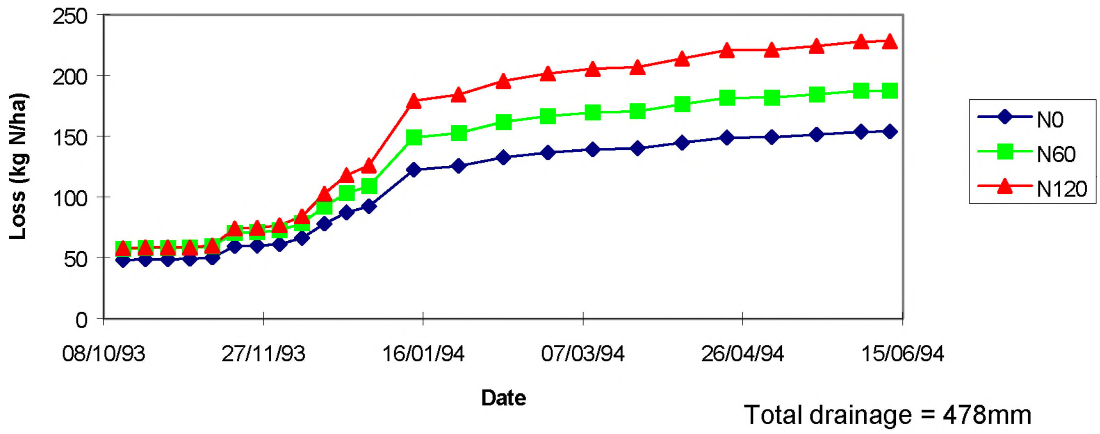
Figure 8.7 Soil surface and 10cm deep temperatures (°C) within two Miscanthus plantation densities (0.75m and 0.5m spacing). Measurements taken over the period 17-20 June 1995.



8.3 Nitrate Leaching and N Balance in *Miscanthus x giganteus*

At Rothamsted, the nitrate (N03) content in soil solution was measured under each plot by collecting samples of the soil water using ceramic suction cups installed to a depth of 90cm in each plot. The samples were collected at frequent intervals throughout the winter and an estimate of nitrate-N loss made by using meteorological data. Results are given in figs 8.8 and 8.9 for 1993/94 and 1994/95 respectively.

Figure 8.8 Cumulative leaching losses of nitrate-N from miscanthus in winter 1993/94



The study shows that over the 1993/94 winter the leaching losses were high in all plots, probably because the previous crop was beans, which leaves higher levels of residual N than cereals. The highest leaching losses were associated with the treatments that received fertiliser nitrogen. Nitrate lost was not in proportion to the amount of fertiliser applied. The reason for this is not clear. The amount of nitrogen applied to crops was set by the experimental protocol and this along with the residual soil mineral N may have been in excess of crop needs during the establishment period. Therefore surplus N was available at the end of the season to be leached through the soil profile. Over wintering losses in 1994/95 were lower than in 1993/94 (fig 8.9).

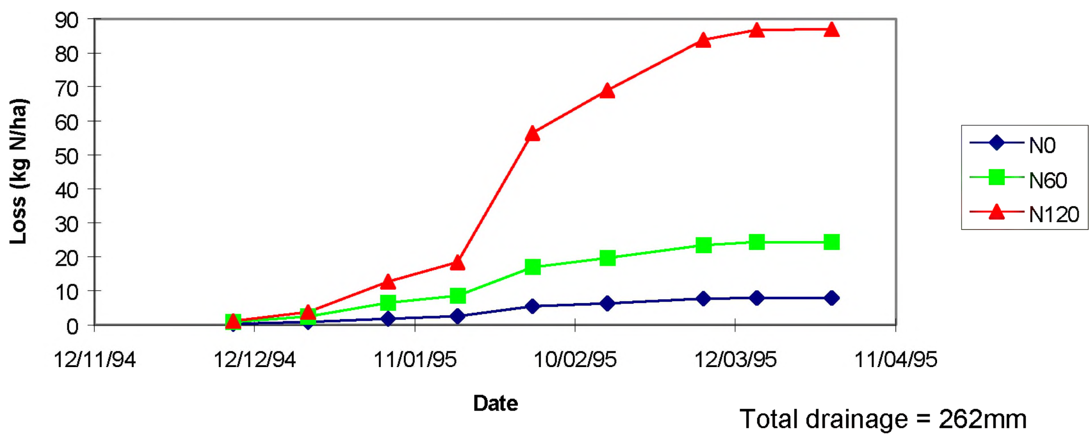
A crude mass balance can be constructed from the data collected and using estimates of soil N losses by leaching or by soil sampling (Table 8.6 and 8.7). The porous cup probe method and soil sampling were used to estimate losses of N during the winter drainage period. In August 1993 the soil mineral N content reflected the addition of fertiliser N at the different rates in the previous spring. Crop uptakes accounted for 78 kg N ha^{-1} and over winter nitrate-N losses increased with the higher rates of N applied. Both methods of estimating N loss were in reasonable agreement. In 1994 N uptakes in the crop increased with increasing amounts of N applied. In spring 1995 the N content of the soil was similar in the three treatments indicating that the surplus N was probably lost by leaching. Table 8.7 shows leaching losses to be greater in proportion to the amount of fertiliser N applied. Differences not accounted for were the same for the control and N120 treatments, but the balance was best for the N60 treatment, possibly because the N content of the roots and rhizomes was measured and not estimated.

Table 8.6. Uptake and soil losses of nitrogen under Miscanthus. August 1993 - April 1994.

	Treatment		
	N0	N60	N120
N in soil in August 0-90cm, kg ha^{-1}	203	271	344
N in crop, kg ha^{-1} Stems and leaves	25	25	33
Roots and Rhizomes* kg ha^{-1}	45	45	45
N losses soil estimate kg ha^{-1}	117	168	246
N losses cup estimate kg ha^{-1}	154	187	228
N accounted for (%) By soil sampling	92	88	94
By leaching estimate %	110	95	87

* estimated from crops receiving 60kgN ha^{-1} as fertiliser.

Figure 8.10. Cumulative losses of nitrate-N from *Miscanthus x giganteus* in winter, 1994-5.



Total drainage = 262mm

Table 8.7. Nitrogen budget for Miscanthus in 1994/95 calculated from Rothamsted data. All data in kg N ha^{-1}.

Date	N source	Added or removed from system	Treatment N0	N60	N120
Spring 1994	Root and rhizome	+	44	45	59
	Soil	+	87	103	98
Summer 1994	Fertilizer	+	0	60	120
1994/95	Atmospheric deposition	+	40	40	40
Winter 1994/95	Leaching	-	8	24	87
	Litter	-	18	15	18
	Crop offtake	-	48	57	74
	Root and rhizome*	-	84	98	128
Spring 1995	Soil	-	57	65	53
	UNACCOUNTED		-43	-10	-43

* estimated from crops receiving 60kgN/ha as fertiliser

9. SUMMARY AND CONCLUSIONS

It is appropriate to review the objectives of this project as described in the Contract document:

1. To quantify the yield potential of *Miscanthus x giganteus* at three sites in southern England.

2. To evaluate the relationship between climate and yield potential throughout Europe by participating in the EC Miscanthus Productivity Network and following a common experimental protocol.

3. To evaluate other plant genera selected on the basis of their promising potential as biomass crops.

4. To assess the environmental impact of growing and harvesting biomass crops by measuring crop growth, habitat value and biodiversity and identify adverse effects on the rural community.

Within the framework of the project we have achieved more than anticipated in many areas, and decisions on the value of most species as biomass crops can be made. The results of the study are showing that grasses, especially Miscanthus, are better potential biomass crops than the dicotyledonous crops so far tested. These crops have proved to be low in yield. In addition to Miscanthus, the species showing promise are *Phalaris arundinacea, Spartina* spp. and *Panicum virgatum*.

Miscanthus x giganteus is showing great promise, both in the UK and Europe in general. Miscanthus requires two-three or more years to reach physiological or yield maturity, depending on the original form of planting material, after which maximum yield may be identified.

Data from the European Miscanthus Productivity Network suggests that there is a definite future for Miscanthus spp. as a biomass crop. As with all promising biomass species, the major task ahead is that of defining the most appropriate management strategy which will combine high productivity with low-input technology. This will need to focus on the provision of robust, inexpensive planting material and the development of locally adapted, high yielding, physically homogenous varieties. On the basis of the limited information available accross Europe at the moment, it appears likely that mature yields of 15-20 t ha^{-1} yr^{-1} may be realistic. The species converts solar radiation and fixes harvestable carbon efficiently and cycles nutrients effectively so that off-take figures and fertiliser requirements are relatively low. Canopy development at the start of the season is slow, which is to be expected from a C_4 species, even a low temperature tolerant one like Miscanthus, and the developing canopy is suseptible to frost damage. It is likely that a planting density 4 plants/m^2 is higher than necessary.

It must be remembered that the M. x *giganteus* material under assessment was not genetically improved or selected. We must, therefore, assume that great potential exists for increasing yield and the climatic range of the crop by breeding.

Pests and diseases in the crops have been found to be minimal. However, the crops density associated with small plots is unlikely to lead to disease pressures. It would be important to plant larger areas of the best candidate species to test pest and disease pressures. Larger plot areas would also enable better evaluation of the crops. Weed control in Miscanthus did not present problems past establishment. Indded, once established, Miscanthus may require only one springtime application annually.

The 1995/96 yields from the replicated screen of *Phalaris arundinacea* were extremely encouraging. Herbicidal control of weeds was not required, spring regrowth was early and rapid allowing an early cut and subsequent aftermath cut, as well as an end of season harvest. As with the other energy crops studied at Rickwood, there was no apparent response to N fertiliser level.

As information is obtained on the phenology of the different crops the prospects of increasing bio-diversity in biomass crops will become clear. The information already obtained on Miscanthus, for example, shows that the production site is likely to have an important influence on yield.

Phalaris has produced more biomass in the first year of growth than any other of the crops being evaluated, with no demonstrable winter losses. Unlike Miscanthus and Spartina, *Phalaris* can currently be readily established by seed. Establishing crops by seed will reduce costs of production and open up prospects of integrating crops in a farm rotation. For those species which required transplanting, the importance of the culture medium and immediate post-transplanting treatment has been seen. This was particularly apparent with the Miscanthus material. Experience gained at Rothamsted shows that more understanding of establishing the crop is required if uneven germination and growth is to be avoided. The large-scale experiment at Rickwood has indicated that high annual yields are possible and that one cut per season maximises yield. This crop has great potential.

We have been able to define a number of potential problems for these species which need to be addressed immediately. Many species, most notably *Panicum virgatum, Phalaris arundinacea, Echinochloa frumentacea, Sorghum saccharatum*, exhibited slow, protracted germination. This may have been because soil temperatures did not achieve suitably high temperatures during spring 1993. As a consequence of the delayed germination of these species, competition with weed species was poor, and all required chemical or cultural weed control. As they are novel species, there is an absence of label recommendations for herbicides. This may lead to inappropriate applications.

Studies of nitrate leaching have illustrated the risk of over winter losses of nitrate in immature crops. The risk may change with time as the 'memory' effect of previous cropping diminishes. However the rate and timing of nitrogen requires to be studied in more detail to identify methods of minimising nitrogen losses and protecting the environment requires further study. Environmental impact assessment are being studied but it appears that Miscanthus may not lead to a significant loss in bio-diversity. Preliminary information suggets that mature Miscanthus stands may significantly reduce leaward wind speeds. Further information is required from large-scale plantings. As such a long-lived crop, trials should concentrate on modification of the local climate, particularly wind; leaching of nitrate and pesticides; ingression of species into the natural environment and vertebrate and invertebrate diversity within crops. There is a clear need to define the energy ratios for these new biomass species.

A number of species have been found to be inappropriate as biomass crop species. These failures have been for two reasons; high moisture content at harvest or low biomass productivity. Those failing on grounds of high moisture content were *Zea mays, Sorghum bicolor, Echinocloa frumentacea, Helianthus tuberosum*. Those failing due to low biomass productivity were *Echinops ritro, Sorghum bicolor*. *Miscanthus sinensis* 'Goliath' suffered heavy winter kill in the UK - however, evidence from re-planting and information from Europe on the productivity of Goliath indicate that this variety failed because of poor quality planting material, not an inherent inability to grow in UK conditions.

The following conclusions can be drawn from the three year results of the Rosewarne unreplicated field plots; yields were very low compared to other more fertile sites, when compared to other varieties grown on this site *Miscanthus x giganteus* yield was poor and onset of senescence late, *Spartina pectinata* and *Arundo donax* were suitable crops for this site.

Finally, the replicated trials have produced important results. The possible contribution of whole crop winter cereals to energy production systems warrants further investigation - yields from whole crop cereals in this study equalled the productivity of the specialist biomass crops. However, low energy ratios and philosophical considerations pertaining to the 'burning of food' may in the long term make these crops unviable as energy sources.

Further investigations of the agronomy, physiology and environmental impact of Miscanthus, Panicum, Phalaris and possibly Spartina in field scale experiments is warranted. Studies are already in place which will provide details of the geographic range and yield profile of Miscanthus in the UK; these studies should be duplicated with the other three species.

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Duchy College of Agriculture, Cornwall.

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12. APPENDIX 1

Julian days

(Add one day after Feburary 28 in leap years)

DAY OF YEAR CALENDAR

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
JAN	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
FEB	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60		
MAR	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90
APR	91	92	93	94	95	96	97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120	
MAY	121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144	145	146	147	148	149	150	151
JUN	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168	169	170	171	172	173	174	175	176	177	178	179	180	181	
JUL	182	183	184	185	186	187	188	189	190	191	192	193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209	210	211	212
AUG	213	214	215	216	217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233	234	235	236	237	238	239	240	241	242	243
SEP	244	245	246	247	248	249	250	251	252	253	254	255	256	257	258	259	260	261	262	263	264	265	266	267	268	269	270	271	272	273	
OCT	274	275	276	277	278	279	280	281	282	283	284	285	286	287	288	289	290	291	292	293	294	295	296	297	298	299	300	301	302	303	304
NOV	305	306	307	308	309	310	311	312	313	314	315	316	317	318	319	320	321	322	323	324	325	326	327	328	329	330	331	332	333	334	
DEC	335	336	337	338	339	340	341	342	343	344	345	346	347	348	349	350	351	352	353	354	355	356	357	358	359	360	361	362	363	364	365