Optimising Harvesting and Storage Systems for Energy Crops in The Netherlands.

W. Huisman,
Wageningen University, Netherlands, Dept. Agrotechnology and Food Science,
Farm Technology Group.

Paper presented at the International Conference on Crop Harvesting and Processing, February 9-11, 2003, Louisville, Kentucky, USA

Abstract

For perennial crops like short rotation coppice (in particular willow), rhizomatous grasses (like miscanthus, switch grass and reed canary grass) as well as the annual crop hemp all operations for harvesting and storage are discussed. These are mowing, size reduction, densification, conservation, storage and pre-treatment. The requirements for energy conversion and co-firing are given and the effect of harvest conditions or quality is shown. The best production chains for average conditions of the selected crops are introduced for Dutch conditions. However many more different production chains are possible. The choice of the best system depends on the local conditions and chosen optimization criteria. The optimization in the selection of methods and chains is only possible by means of modeling for local conditions. This should include the input of the variation of the weather for a long period in the model. The design of a simulation model for this purpose is illustrated.

KEYWORDS. Biomass, harvesting, storage, conservation, optimisation, miscanthus, reed canary grass, willow, hemp.

Introduction

Biomass crops for energy production can be produced in many ways. The choice of the best harvest and storage methods is defined by many conditions like: Requirements of the applied fuel conversion technology, requirements as defined by co-firing, local climate, available technology, transport infrastructure, cost levels of the various inputs, available subsidies. The selection criteria can be: minimal costs or energy input, maximum financial or environmental profit or maximum energy output. The selection process should be based on optimisation of the whole chain, including pre-processing, rather than on single operations. A simulation model is being built to support the selection of the optimal production chain.

In this paper the farm operations of harvest and subsequent drying, storage and pre-treatment will be presented in order to discuss the aspects related to the optimisation of bio-energy chains from the farm to the gate of the conversion plant.

The energy crops under consideration

This paper will deal with fibre crops for direct combustion or gasification. We consider the perennial grasses: miscanthus, reed canary grass and switchgrass, the short rotation woody crop: willow and the annual crop: hemp. The advantage of an annual crop is that after the decision to produce is taken, in just one season the required biomass can be produced.

Miscanthus

Extensive fields trials of *Miscanthus x giganteus* Greef et Deu. , a sterile hybrid genotype of the large perennial grass miscanthus, have been carried out in northern Europe since 1983. The yield potential of this novel annually harvested bioenergy crop has been shown to be substantial, but some concerns remain about drawbacks such as its relatively high establishment costs and its currently narrow genetic base.

Miscanthus was first cultivated in Europe in the 1930s, as an ornamental introduction from Japan. A number of other ornamental varieties of miscanthus are also known to exist under various common names. The yield potential of miscanthus for cellulose fiber production was investigated in the late 1960s in Denmark. Trials for bioenergy production commenced in Denmark in 1983, spreading to Germany in 1987 before more widespread evaluation throughout Europe. Possessing the efficient C_4 photosynthetic pathway (with relatively low nutrient and water requirements), yet tolerant of cool temperate climates, miscanthus is potentially an “ideal” energy crop with a plant length of 2-4 m. The highest aboveground standing biomass is found at the end of each growing season (up to 20-30 t/ha dry weight), but it is usually considered desirable to allow the crop to dry out over winter, with losses of 30-50% of the standing biomass. Such losses are tolerated because of the resulting improvements in fuel quality. Moisture content may drop to as low as 15% by early spring. The final annual yield at harvest is therefore up to 12-18 t/ha (dry weight, t=Mg), although large-scale semi-commercial trials suggest about 7-9 t/ha (dry weight) is a more reasonable estimate over large areas. Rotations are estimated to be from 15 to 25 years, although most older trial stands are only in their 6^{th} to 8^{th} year of cropping, and few European stands can be more than 10 years old.
The miscanthus crop is established by planting mechanically divided rhizomes, or plantlets micro-propagated in tissue culture. Mechanically divided rhizome pieces may be collected with a potato or flower bulb harvester from nursery fields (preferably with sandy soils for ease of tilling), planted at a density of 3-6 plants/m^2. (Lewandowski et al 2000).

Switchgrass. Switchgrass (*Panicum virgatum* L.) is a native perennial warm season, C_4 grass that was some of the three major grasses found in the North American tall grass prairie. It is a course-stemmed plant that grows 1 to 2 m tall. The many varieties are adapted to the specific local conditions like temperature, day length and precipitation and the yield varies between 8 and 20 t/ha (dry weight). Switchgrass is established by seed, has a low nutrient demand, efficient water use and good persistence. Experiments were performed only on a small scale in The Netherlands.

Reed canary grass. In Sweden and Finland reed canary grass (*Phalaris arundinacea* L.), has been recognised as a possible crop for paper pulp and energy before 1990. Projects started in 1991 in both countries (Saijonkari-Pahkala 2001). The yield in Finland was 7-8 t/ha on clay soils and over 10 t/ha on organic soils after the second harvest year. Sandy soils are also suitable when enough water is available. The crop preferes wet growing conditions. Most promising varieties for fibre were Palaton, Vantage and Lara. Other varieties for fodder have more leaves, while yield is the same. Establishment of the crop is done by sowing (without a cover crop) 1000 seeds/m^2 in autumn or spring when enough rainfall is available (Pahkala 1996). Sowing should be very shallow (1cm) since seeds require light for emergence. Harvest can start in September but when harvested consequently in spring, yields are higher. In The Netherlands only experiments were performed on a small scale.

Willow coppice. Willow *(Salix viminalis* L.*)*, a perennial woody crop with a full production cycle of 20-25 years, is also a suitable crop which can be grown well under Northern and Western European climatological conditions. Planting whole stems horizontally or stem pieces of 25 cm vertically establish the crop. At harvest, which takes place every 3 to 5 years between November and April the moisture content is 50% wb (wb = kg water/kg total). The expected maximum yield is 8 to 12 tons dry matter per ha annually.

Hemp. Hemp (*Cannabis sativa* L.*)* has been a fibre crop for many centuries. In the seventh and eighteenth centuries hemp was in great demand for making ropes, sails and fishing nets. In the twentieth century fibre hemp all but disappeared from North West Europe and America, except for France. In China and Russia it continued to be used as fine textile fibre. Production started again in Europe from 1990 on a small scale in different countries. It became used for paper pulp, textile and in the automobile industry in construction materials. Because of its high potential yield of 15 t/ha dry weight (in field plots) it is also a potential energy crop. The annual, short day, C_3 crop is propagated using seeds and does not require much control for weeds and diseases. (Werf, 1994). The crop has a stiff stem and has a length of 2.5-5 m.

Product quality requirements

The applied conversion technology defines the required product quality and shape. On the other hand when the total chain is optimised the installation for conversion is variable too. For co-firing the requirements are also defined by the other fuel. In most cases there is a need for separate feed of the biomass fuel.

In general the moisture content should be less than 10%. In bubbling fluidised bed combustion systems higher moisture content of chips, up to 40% is possible. This implies drying somewhere in the chain. Mineral content, especially Cl, N, P, K and Si should also be low, alleviating the problems that elements such as potassium and chlorine may cause in biomass fuel processing. This can also be influenced by low-level fertilisation of the crop. Impurities like sand should be avoided for low wear of installation parts and low ash content. Separation or washing can be necessary. Size and shape should be optimised for combustion and fuel feeding. Especially in case of gasification, airtight supply or dosing of mass should be possible. Pellets, chips or chunks can be made either in the harvesting or in the combustion pre-treatment operations. Compacting by pelletising, briquetting or baling increases density and so decreases handling and storage costs.

Influence of harvest conditions

The crop properties depend on harvest time and location. Important properties are:
Moisture content. For a certain energy conversion technique, the maximum moisture content is defined. Higher moisture content of plant pieces increases the risk for wrapping during handling. The moisture content of grasses is decreasing during wintertime and springtime. When waiting for harvest until spring the crop is dried naturally, with resultant advantages in handling and little need for further drying. Ash and mineral content are also reduced (since many nutrients are recycled through leaf drop and re-translocation to the rhizomes). The decrease of moisture content during wintertime and springtime of reed canary grass is in Finland and Sweden such that after the snow has melted 10-20% w.b. is reached. In Western Europe this is much higher. For miscanthus in The Netherlands the moisture content decreases from 80% in October through 40% in March till 10% in late April. (Huisman and Kortleve, 1994). Willow and hemp only dry after cutting or mowing.

Dry matter losses. After the crop has finished producing dry matter, loss of dry matter takes place during the period of drying by dropping leaves and other parts like tops of the plant on the ground. After composting, the minerals in this lost material will be available for subsequent production cycles. The harvestable yield of miscanthus decreases roughly linearly with 0.28% per day from October 1st.

Structure of harvested material. By loss of leaves the structure and average composition of the dry matter changes, generally in favor of the conversion quality since the content of minerals in the leaves is higher than in stems.

Translocation of minerals. At the end of the growing season the plants start to reallocate minerals to the rhizomes and roots. In this way the content of these minerals in the harvested matter decreases. Also minerals are leached during wintertime or drying in then field. Two examples are given in table 1.

Table 1. Change in mineral content (%of d.m.) in biomass in the field during wintertime

Phalaris: In Sweden:(Ollson, 1994)

Material	Before winter	After winter
N	1.33	0.88
P	0.17	0.11
K	1.23	0.27
Cl	0.56	0.09
Si	1.20	1.85
Ash def T	1074 ^{o}C	1404 ^{o}C

Miscanthus (Netherlands)

Material	At 19/11/97	At 29/1/98
N	0.47	0.36
P	0.06	0.00
K	1.22	0.96
Cl	0.56	0.09
Sugers	0.30	2.07
Starch	0.70	0.14

Mowing

The first action at harvest is generally mowing, i.e. separating the stems from the roots and putting the material in good condition for the next operation.

Possible machines for mowing are:

Swath mower, cutter bar, disc mower, disk mower conditioner, flail mower, maize mower and special mowers, cutters and saws. Important aspects when comparing these systems are:

* Availability of machines. Very often the first choice of a machine is defined by the availability in current agricultural practice of that area. However when large areas will be harvested it has more sense to select from all available types of machines, to improve them if necessary, or even

to design new machines. In this way product quality can be improved by optimal choice of the machine or adaptation to the crop.
* Minimum possible cutting height. In order to harvest as much material as possible, special mowers have to be developed for miscanthus since the plant can be cut just above the soil, without damaging the roots. The lower the cutting height the more pollution with soil can be expected. Data about cutting height and losses are for instance: for reed canary grass in Finland (Pahkala 1998): Harvested mass is 40% lower for 10cm cutting height compared to 5 cm cutting height in first week of May. This is 20% for the last week in May. For miscanthus in The Netherlands the cutting height losses are about 0.55% per cm higher cutting height.
* Loss of small pieces. In case the small grasses are mowed when it is very dry, and so the material is very brittle, broken pieces fall on the ground and cannot be collected anymore. A mower conditioner is not advised in these conditions. Mowing-baling or mowing-chopping in a combined machine is favorable then.
* The machines should leave a good swath for the next operation or if additional drying is required after mowing in order to minimize losses and pollution with soil.
* Handling lodged crop. The machines must also be able to harvest lodged crops, for instance due to heavy snow layers or storms. Flail mowers can take up any crop but give short pieces that can be lost when the material is put in a swath and increase pollution with soil.
* Handling fallen leaves. When maximum yield is wanted, the fallen leaves can be gathered by mowing lowly. In that case moisture content will be higher and the content of soil and minerals in the collected matter will be higher. Then also less minerals are recycled by decomposition, so more fertilizer should be applied then.
* Separation of soil or undesired plant parts should take place on the machine so they can remain at the field.
* Combination with next operations. If possible, mowing should be combined with one or more of the following operation in one machine. Especially when no drying in a swath is required it is advised not to leave the crop on the ground in order to avoid contamination.

Size reduction

Reduction of size can be necessary for the conversion technology or can be beneficial for handling. If length of stem pieces is below 50 cm, the bulk can be handled as a flowing material. The shorter the product is cut, the higher the density in storage and in bales, reducing cost for handling (including dosing) and storage. Handling of whole stems of miscanthus, hemp and willow is difficult. On the other hand drying of short pieces in bulk is difficult also since the air resistance increases the shorter the length of stem pieces. In case of hemp, miscanthus and willow, stem lengths between 50 and 250 mm (called chunks) and whole stems permit natural drying in bulk (not for hemp). Size reduction can be performed by various machines:

Conditioners. The crushing conditioners usually are used to increase drying speed after cutting. After conditioning the particle length has also decreased but the length distribution is very wide.

For hemp and miscanthus, conditioning also improves the ease of handling, for instance for baling.

Choppers / forage harvesters. In these machines the particle length can be adjusted between roughly 0.4 and 5 cm. The shorter the chopping length is adjusted the more dust will be produced and the more losses can occur in case of strong wind while loading the trucks. Also hemp could be harvested successfully in this way when the chopper is of the drum type.

Hammer mills. These machines can be used stationary to get lengths below 0.5 cm. The resulting length distribution depends on the use and size of screens.

Chunking machines. Sugar cane harvesters or special designed machines can make chunks. For hemp a special machine has been developed, based on a forage harvester, that cuts the mowed stems in pieces of 50 cm and breaks the stems in the middle. In this way the material can be picked up easier than whole stems, wrapping does not occur, even transport by augers is possible. A swath formed by this machine is loose and open and dries quickly due to the low density. Also a prototype miscanthus harvester with low cutting device (Claas) shortens the material in pieces of about 50 cm.

Densification

The main reason for densification is to make units for easier handling and with higher density than loose material. The higher the density however, the less possibilities for natural or mechanical drying are available. The density in storage will differ from the density in the units if these are not square. There are several principles:
Baling. Using standard farm machines for straw or hay the following densities in kg dry matter per m^3 will be reached in miscanthus: Round bales 100-130 (Reed canary grass: 170), Square bales 130-160, A test was done with chopped miscanthus in a high density baler. The density then became more than 250 kg d.m./m^3

Pelleting. Generally such machines are used stationary, however a prototype mobile pelleting machine was designed in Germany (Hartman 1998) and used to test harvesting whole grain crops and miscanthus for energy. The density in the pellets was 875 kg d.m./m^3 and in bulk 380 kg d.m./m^3 The same densities are expected for the grass crops.
With a stationary pelleting machine a bulk density of 500 kg d.m./m^3 was reached in miscanthus.

Briquetting. In briquets a density of 600 kg d.m. / m^3 was reached.

Bundling. In The Netherlands miscanthus was harvested with a self-propelled reed mowing and bundling machine. In the bundles with a diameter of 25 cm the density was about 100 kg d.m./$m^{3.}$ Such bundles were put together in large bundles with a diameter of 1.5 m. If such bundles are stored next to each other in a long row (stems perpendicular on the long row) and 2 or more layers on top of each other, the material will dry by natural ventilation.

Whole stems on a pile. Willow stems can be harvested by a machine that collects the whole stems in a bin which can be unloaded at regular intervals for instance at headlands where it can dry by natural ventilation. (Gigler 2000)

Conservation

During storage the quality and quantity of the product should be maintained by conservation. Drying is a common method for conservation, but also sealed storage, called ensiling at which lactic acid fermentation occurs, can be applied for wet (or partly dry) biomass, including willow.

Drying. For dry storage, moisture content should be below 15% to prevent fungal growth. Spontaneous heating will occur at moisture contents above 25% unless continuous ventilation is applied. The methods for drying are: Field drying by sun radiation, natural drying in storage with ambient air both indoors and outdoors (when covered somehow), mechanical ventilation with a fan using ambient air, thermal ventilation with fan and heated air, in industrial dryers (possibly using waste heat) and combinations of these methods, successively. Costs increase in this order. Natural drying of bales is possible if density in the bales is less than 120 kg d.m./m^3, the outdoor pile is covered and not too large and between the bales some space is provided. Also drying of biomass in potato storerooms is possible when density is not too high.

Ensiling. This is natural lactic acid fermentation in anaerobic conditions. If sealing will be done at the same day of harvest no spontaneous heating will occur and losses are less than 1%. The pH level should decrease to 4 (high moisture content) or 5 (at moisture contents lower than 50%. When continuously kept in anaerobic condition, conservation will last for years without additional loss. Coverage with plastic sheeting is sufficient for short chip lengths. Longer pieces of hard stems will perforate the plastic, so tarpaulin is necessary then. A change of nutrient contents in silage during storage was found for Cl that decreased from 0.5 to 0.1 % d.m. content.

Storage

During dry storage it is necessary to protect the harvested material against precipitation. This can be done by coverage by waste materials, plastic sheeting, and tarpaulin or in buildings. When no coverage is applied the outer layer of product gets wet but protects the lower layers of product. Except for chunks and whole stems the outer layer is considered to be lost and generally involves also additional costs for disposal.
The waste material absorbs or drains the rainwater. Materials like sawdust, chicken manure, steamed potato peels are under investigation for coverage of chopped product. Chopped switchgrass can be stored uncovered since the pile sheds rain. Plastic sheeting can be applied for

chopped material and short storage of bales for thin grasses. Bales of miscanthus and hemp need tarpaulins to prevent damage by the sharp stems. Plastic sheeting and tarps are cheap, but involve laborious methods, which require much inspection and repair after storms. Storage in structures requires more investments, but just covering and simple roof structures are sufficient and even recommended for natural ventilation.

In a study on storage of large quantities of rice straw in California USA, six different systems were compared: no coverage (outer bales lost), coverage by tarpaulin, pole barns (no walls), metal buildings (with walls), fabric buildings and truss arches. (Huisman, 2000). Also 4 levels of average storage capacity in these systems were chosen: 800, 4,000, 20,000 and 100,000 t for both large bales and small bales. It was concluded that storage in big bales and in the larger storage capacities is cheaper. Storage in metal buildings demands the highest investments but results in the lowest costs (of 3.8 $\$t^{-1}$ for big bales and 8.1 $\$t^{-1}$ for small bales) and a higher quality and so higher value of the product stored. The order of increasing costs is pole barns, metal buildings, tarpaulins, truss arches and fabric buildings.

The same conclusions can be drawn for other kinds of “straw” and in other conditions. For Dutch conditions bales are stored cheapest in truss arch type semi permanent buildings. Chips can be stored best under plastic sheeting since it is easy to fix the plastic storm proof.

Pretreatment

Depending on the application and processing techniques some pretreatment can be necessary. This can be done combined with the harvest, after storage on the farm or at the plant.

Leaf removal. The leaves have higher mineral, SiO_2 and ash content. It is possible to separate them by air separation techniques. Hemming (1998) tested this for reed canary grass.

Mechanical dehydration. Fresh biomass or ensiled material has high moisture contents. Water can be squeezed out by a press to a moisture content of 39% w.b. in chopped ensiled miscanthus (Huisman & Kikstra 2002). About 45% of the initial moisture is removed in that case. Dehydration in this research was done with a piston and a screw press. With a piston press (with a pressure of $60 \cdot 10^5$ N/m^2) it is possible to decrease the moisture content from 55% to 45%. With the screw press, a moisture-content of 37% was reached. Together with the moisture also a part of the present minerals will be removed. The piston press removed 35% of the N and P content, 47% of K and 56% of Cl. The screw press removed 35% of N, 44% of P, 56% of K and 44% of the Cl content.

Harvest chains.

Miscanthus. The above ground crop of Miscanthus dies at the end of the summer or after the first frost in autumn. This is the beginning of the drying period. Depending on weather conditions, the moisture content drops gradually from 70% to 10-20% in April. Existing harvesting machines can be used and were tested. After or combined with mowing three handling methods can be chosen: chopping, baling or bundling. The last method is not advised for bio-energy use. Figure 1 shows the relevant chains for harvest-conversion of miscanthus.

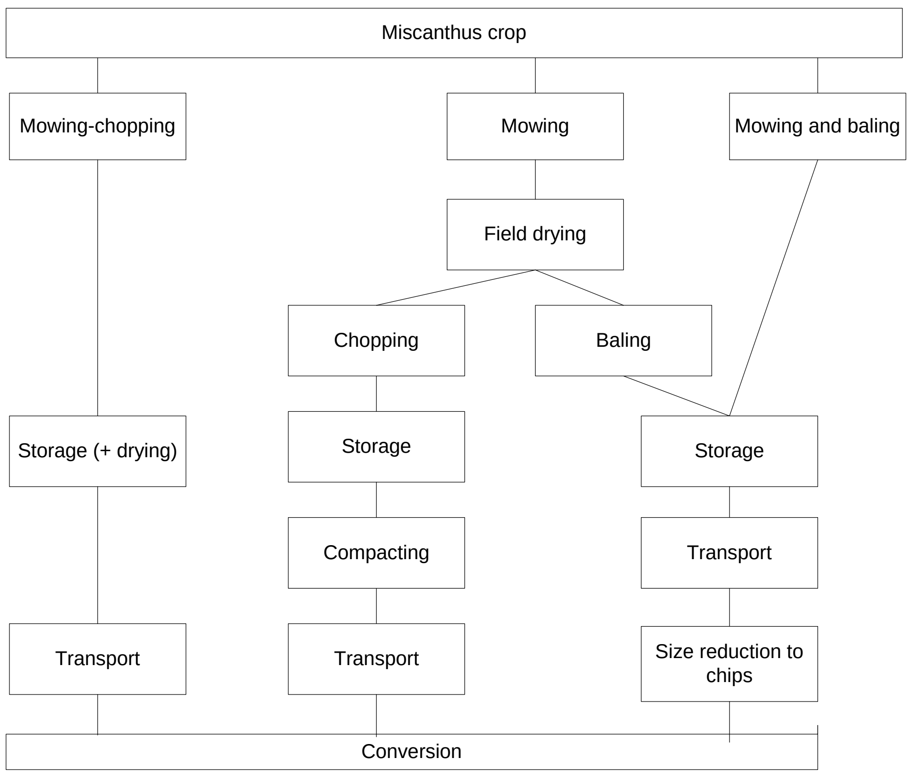

Figure 1. Chains for harvest to conversion of miscanthus

Mowing and chopping. A chopping self-propelled forage harvester used for harvesting silage maize or grass can also be applied in the harvesting of miscanthus. In an older crop the rows are not distinguishable any more so a row independent mowing attachment is required. Experiments with a Kemper 'Champion 3000' mowing attachment gave good results. The material was cut at different lengths of 11 mm and 44 mm which results in a bulk density of 95 kg d.m./m^3 and 70 kg d.m./m^3 respectively. A p.t.o. driven flail type chopper pulled by a tractor has also been tested.

The density after chopping is rather low. Therefore a compacting treatment is introduced as a possible treatment at the farm, just before transport of the crop to the processing plant. Such a machine could be derived from a commonly used stationary recycled paper compactor. In this case the density of the bales was found to be 265 kg d.m./m^3. With such density the transport costs are minimal since the maximum weight load is also reached.

Mowing and baling. Before baling, the crop must be mowed and formed into a swath. The usual method is to use a swath mower of the cutter bar or disc type. Due to broken pieces and problems with picking up the product properly, the field losses were found to be 10-30%. Also a flail type mower-chopper attached in front of the baler was tested. This works well, especially when working on a pull type baler at the side of the tractor. Mowers mounted in front of a self-propelled baler are recommended in order to reduce pick-up losses. This should be a row-independent mowing attachment for forage harvesters. To enable a lower cutting height, an experimental mower, based upon the sugar cane harvester was developed by Claas. (The machine is not at the market). A lower cutting height results in more harvested material, higher leaf content (from fallen leaves) and therefore higher moisture content. Drying in a swath might be a solution for the higher moisture content, but also can increase the soil content.

The different types of balers will produce different densities. According to our experiments the densities in dry matter can vary from 130 kg/m^3 for a round baler to 150 kg/m^3 for a high-pressure big baler. At the moment also self-propelled balers are available at the market in Europe. They can be used very well for miscanthus. Ideal would be if the pick up device of the baler would be replaced by the mower so no crop will be in contact with the soil. In optimisation calculations such machine was supposed to be available.

Safe storage is possible after drying, to moisture content below 15% w.b. Since adequate springtime drying prior to harvest cannot always be assured, arrangements for drying in storage become a necessity. Ambient-air-drying by natural ventilation has proven to be possible for chopped and baled material from moisture contents below 30%. An option is also to dry the chopped product in a potato storage system, ventilated from the floor or existing batch grain dryers using the solar energy collectors sited on the roof. Conservation by ensiling is also possible, combined with mechanical dehydration moisture contents can be reached low enough for bubbling-bed-fluidised gasification.

A cost comparison of various harvest chains (no drying) in miscanthus for Dutch conditions showed that differences are small for the chains explained above for short transport distances. In case transport distances exceed 20km chopped product chains are more expensive than chains with bales. (Venturi et al 1998)

Switch grass and reed canary grass. No experience is available at the moment with harvesting these grasses on a large scale in The Netherlands. Spring harvest is most appropriate. Mowing followed by swath drying, raking and baling or chopping. See figure 2 for the possible chains. Problems can arise when the regrowth occurs before the mowed crop is dry. In such cases collecting the wet material en subsequent drying should be possible. In Finland harvest is done right after snow melting when the crop dries easily.

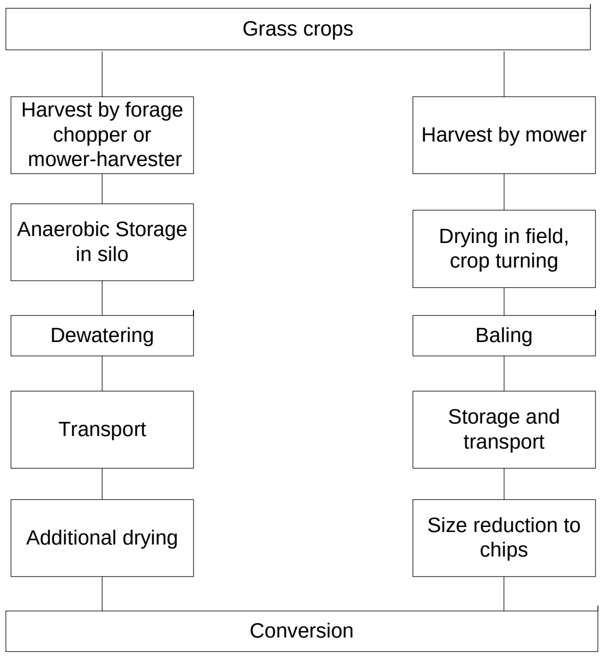

Figure 2. Chains for harvest to conversion of grass crops

Willow. Research by Gigler (2000) showed that the costs and the selection of the production chain of willow depend on the storage duration. See figure 3. Maximum moisture content of 25 % is assumed at conversion. If immediate supply is required the chain consists of: harvest as chips - transportation - thermal drying at the energy plant. Short term supply (within 2 months after harvest) the chain consists of: harvest as chips - forced convective drying at the farm - transportation - storage. For medium term supply (2 – 5 months after harvest): harvest as chunks - natural wind drying on the headland - forced convective drying at the farm – transportation – size reduction to chips (if required). For long term supply (more than 6 months after harvest): harvest as chunks – natural wind drying on the headland – transportation – size reduction to chips. In this order also costs decrease since the drying costs are dominant.

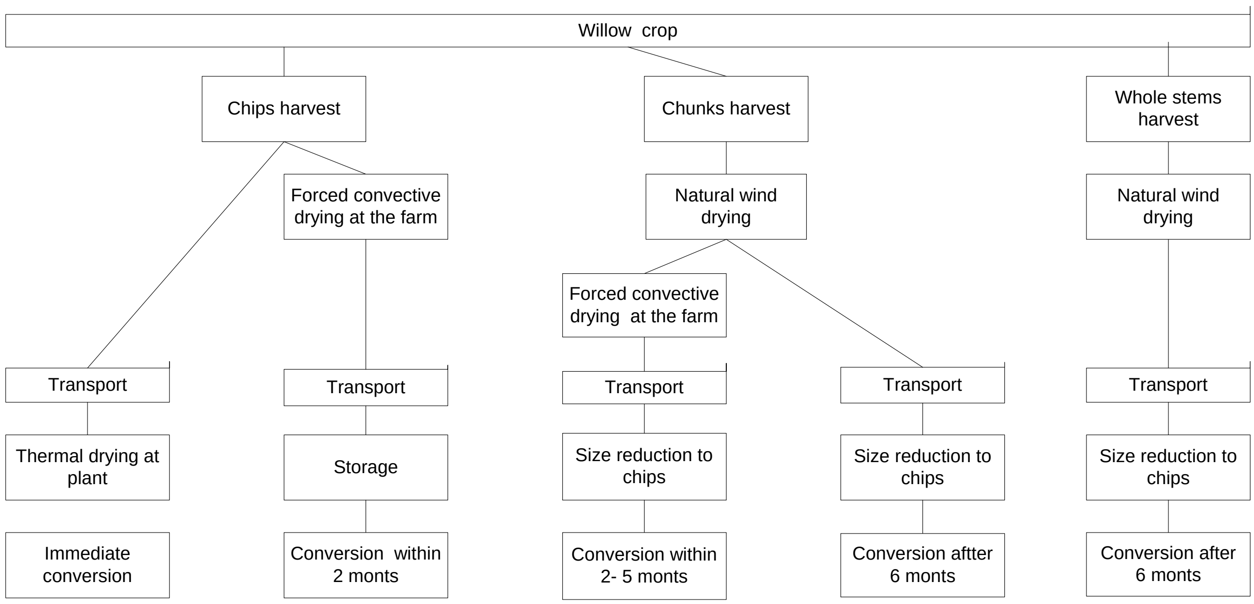

Figure 3. Chains for harvest to conversion of willow

Hemp. Two systems are applied in the Netherlands: the wet storage method is tested successfully (Maeyer1994, Huisman 1995) and the dry storage method is used in practice on 1000 - 2000 ha yearly. See also figure 4.

The wet storage method was developed originally for paper pulp production and is based on chopping the standing crop by self-propelled forage harvesters and ensiling under plastic sheeting. The moisture content then is 70% w.b., thus when applied for energy conversion dewatering by thermal or forced convective drying or mechanical dehydration is necessary. The system is weather independent, assures constant quality and the mechanical dehydration also separates minerals.

The dry storage chain starts with a special mower, consisting of a 3 m wide row independent (rotating) cutting device, originally designed for corn harvest, and a stem cutter that cuts the stems in pieces of 50 cm (20 inches) and breaks the pieces slightly at half length. The hemp is left on the ground behind the machine on a swath that will be turned by a special machine, once or twice a week in order to dry the crop evenly in the field. Depending on the weather conditions drying takes one to two weeks. When moisture content is below 12 % w.b. the crop is baled in big bales for instance by a self propelled baler that picks up 3 swaths. In wet harvest periods however sometimes drying fails completely and crop is lost in the field due to rotting. The quality of the collected material varies with the weather conditions. Not only the moisture content, but also the intensity of leaching and contamination with soil varies with time and place. After storage at the farm or at the conversion unit chopping of the chunks is necessary for easy handling and feeding.

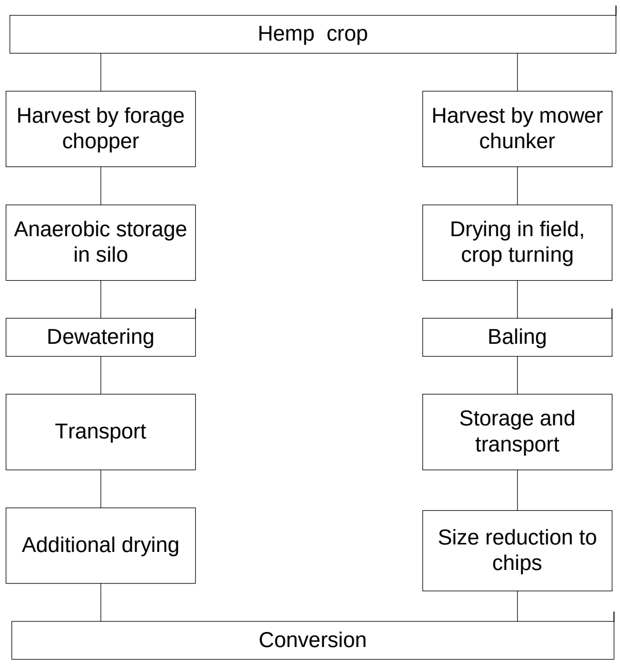

Figure 4. **Chains for harvest to conversion of hemp**

Optimization model

The two different harvest chains of hemp show clearly the dependency of the costs and quality from the local weather conditions. The large variation in weather should be taken into account when selecting optimal chains. Not only results based on average weather are of importance but especially the variation and the extremes are influencing the optimal solution. Therefore an optimization model should include the variation of the weather. Such model is being build and will be explained below on the example of miscanthus.

The harvest of miscanthus can take place from October to spring. In this period moisture content of the crop decreases to such a level that the crop can be stored. For long storage the moisture content needs to be less than 15 %, but for short storage proceeding drying it may be higher. The rate of decrease depends on weather conditions (temperature, precipitation, radiation and wind). When specific moisture content (threshold), as defined by the requirements of a specific production chain, is reached, harvest can start and could continue until the threshold is crossed again (see figure 5).

The threshold level depends on the harvest, storage, drying systems, processing method and final application. For instance, when harvest is performed with a forage harvester, giving a chopped product a higher moisture content can be accepted than for compacting by a baler since artificial drying is possible with chopped product. Harvest may also be interrupted because in wet conditions the soil traffic ability does not permit a normal use of the machines. Traffic ability will depend on the size of the tires and weight of the machines and transport units. In Figure 1 the 'T' shows this.

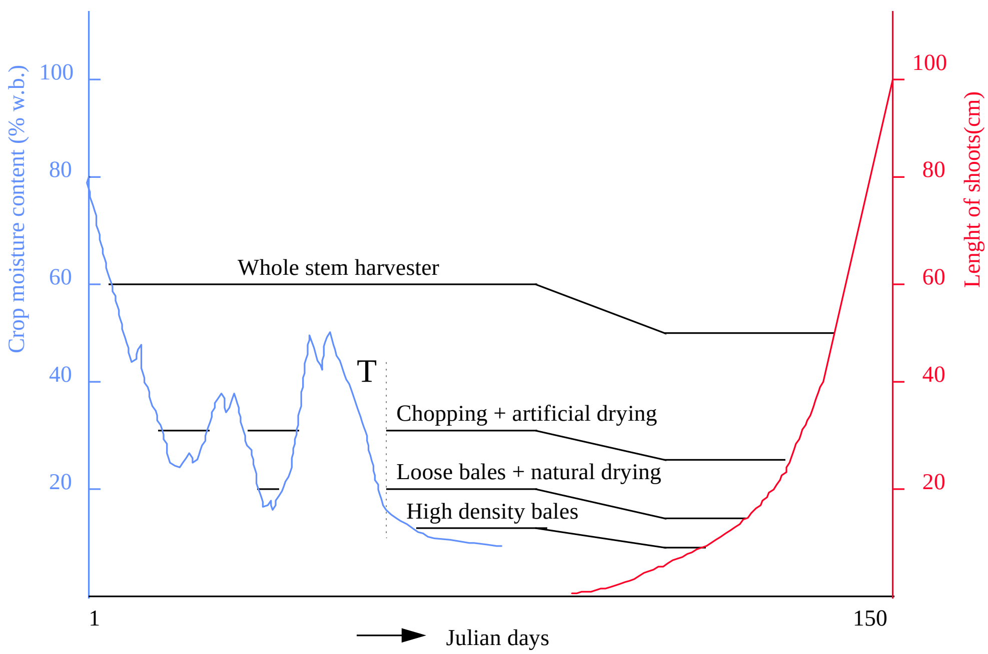

Figure 5. Harvest windows of miscanthus

When the temperature increases in spring, new shoots will emerge. When these grow longer and also are gathered at late harvest, the average moisture content of harvested material will increase. Too much damage or removal of new shoots will result in a decreased yield in the following year(s). The harvest must be finished prior to the date after which unacceptable damage to the sprouts will occur also as a result of field traffic. The amount of damage depends on the harvest method since each method involves different field activity. The total loss of dry matter as a function of harvest moment is called timeliness loss.

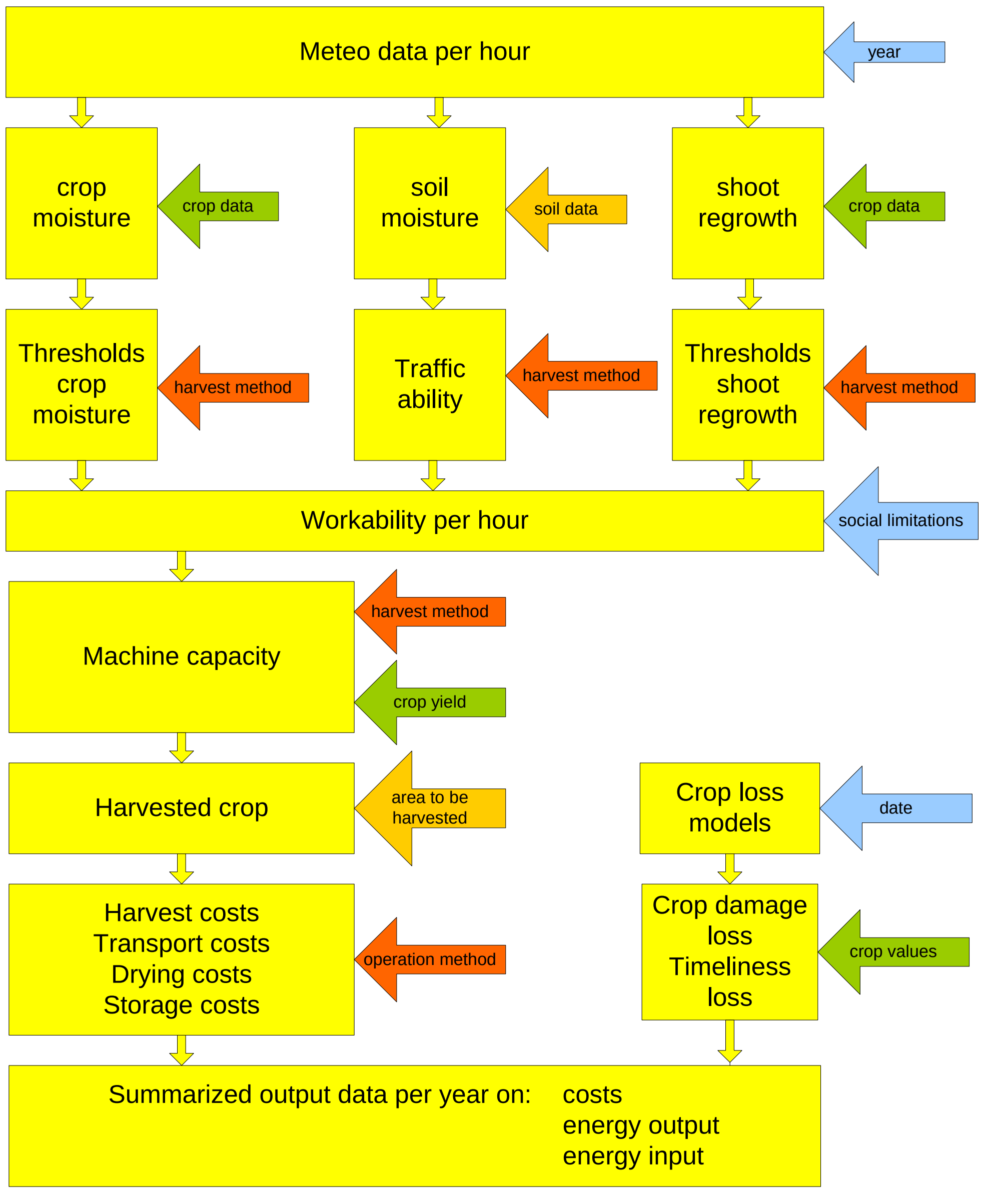

Figure 6. Scheme of the model for optimization of costs of bio-energy chains.

The harvest time available between the defined thresholds is called 'harvest window'. Machine costs are higher the shorter the harvest window is because of the need for larger machine capacity (more or larger machines) to finish in time. Drying costs and storage losses depend on the moisture content of harvested material that varies with the weather conditions at harvest and the amount of harvested new shoots.

In figure 6 the general model is shown for miscanthus. Every block in this figure represents a sub model of which the values of the model parameters depend on the crop under consideration and the chosen conditions. These values can also depend on variety, local production conditions and time. Not all sub models are relevant for all crops. The final outcome is costs in money value, energy output and energy input per ton harvested feedstock, for every simulated year. Since the calculation will be done for many years the variation of this output will also be subject of study. The model is now being worked out in detail and building started using JAVA. A database contains the equations and relationships in the sub models and the data of weather and crop and soil moisture. Varying the input data and details of the chains by hand and judging the results will do optimisation.

Conclusion

Many different production chains are possible and even more chains can be recognized when the relevant transport means, storage locations and conversion requirements and so on are also varied. For most operations generally existing machines and systems can be used but in many cases special machines are better when large quantities have to be harvested. The choice of the best system depends on the local conditions and chosen optimization criteria. These criteria can be: financial yield minus costs, energy input, energy output/input ratio, net energy output, environmental aspects, social aspects, organization structure. The optimization in the selection of methods and chains is only possible by means of modeling for local conditions. This should include the variation of the weather between years for a long period.

References

Gigler, J.K. 2000. *Drying of willow biomass in supply chains.* PhD Dissertation, Wageningen University, The Netherlands: 142 p.

Harms, H.H. 1995. Ernte- und Aufbereitungstechnik von Halmgütern (Harvest and conditioning of stems of cereals and grasses). In *Logistik bei der Nutzung biogener Festbrennstoffe*, Internationale Tagung Stuttgart, 30-31 May, Schriftenreihe “Nachwachensende Rohstoffe” Band 5, Landwirtschaftsverlag GmbH Münster: 23-41

Hartmann, H. 1998. Comparing logistical chains for biofuel delivery - Features and costs of pelleting compared to conventional systems. In *Sustainable Agriculture for Food, Energy and Industry,* Proceedings International conference, Braunschweig, Germany, 1997, Eds N El Bassam, R.K.Behl and B. Prochnow, James & James, London, 1998: 812-818.

Hemming, M. 1998. Options for harvesting and preprocessing of reed canary grass. In *Sustainable Agriculture for Food, Energy and Industry,* Proceedings International conference, Braunschweig, Germany, 1997, Eds. N El Bassam, R.K.Behl and B. Prochnow, James & James, London, 1998: 922-927

Heuvel, E.v.d. 1996. *Pretreatment technologies for energy crops*. Biomass Technology Group, Enschede, The Netherlands.

Huisman, W., and W.J. Kortleve. 1994. Mechanisation of crop establishment, harvest and post harvest conservation of Miscanthus Sinensis Giganteus. *Industrial crops and products*, 2, 1994: 289-297

Huisman, W., E.A.A de Maeyer, and L. Frerichs. 1995. Harvest and storage of hemp. In *Symposium reader of Bioresource hemp '95,* Symposium Frankfurt am Main, Germany, March 2-5 1995, Nova Institut .

Huisman, W., G.J.Kasper, and P. Venturi. 1996. Technical and economical feasibility of the complete production-transport chain of *Miscanthus x Giganteus* as an energy crop. In *Proceedings of First European Energy Crops Overvieuw Conference,* 1996, Enschede, The Netherlands. Biomass technology Group, Enschede: 1-8.

Huisman, W., P., Venturi, and J. Molenaar. 1997. Costs of supply chains of *Miscanthus giganteus*. *Industrial crops and products*: 6, 353-366

Huisman, W., and J.K. Gigler. 1997. Logistics of the biomass fuel chain. *Aspects of Applied Biology* 49, 1997, Biomass and energy crops, 379-387

Huisman, W., and J. Kikstra. 2002. Mineral and moisture extraction by mechanical dehydration of ensiled Miscanthus in the energy-from-wet-biomass chain. Poster presented at the 3rd International Congress and Trade Show Green-Tech 2002 with the 5th European Symposium Industrial Crops and Products, 24-26 April 2002 at the World Horticultural Exhibition Floriade, the Netherlands and submitted to the Journal: *Industrial Crops and Products*.

Huisman, W., Jenkins, B. M., and M. D. Summers. 2002. Cost evaluation of bale storage systems for rice straw. In *Proceedings Bioenergy 2002*, Omnipress Madison, Wisconsin (on CD), Tenth Biennial Bioenergy conference, BIOENERGY 2002, September 22-26, Boise Idaho, USA

Lewandowski, I., J.C. Clifton-Brown, J.M.O. Scurlock, and W., Huisman. 2000. Miscanthus: European experience with a novel energy crop. *Biomass and bioenergy* 19 (4) 2000: 209-227.

Maeyer, E.A.A. and W. Huisman. New technology to harvest and store fibre hemp for paper pulp. *Journal of the International Hemp Association*, 1 nr 2, 1994: 38-40

Olsson, R. 1994. A new concept for reed canary grass production and its combined processing to energy and pulp. In *Paper 6 , Conference Non-wood fires for industry*, 1994, Pira International, Surrey UK: 8p.

Pahkala, K. A., 1998. The timing and stubble height of delayed harvest of Reed Canary Grass grown for energy and fibre use in Finland. In *Biomass for energy and industry,* 10Th European conference and technology exhibition, Würzburg, 1998. Eds. H Kopetz et al, CARMEN, Rimpar, Germany, 1998: 204-206

Saijonkari-Pahkala, K. 2001. *Non-wood plants as raw material for pulp and paper*. Agricultural and food science in Finland, Vol. 10, Supplement No. 1, 2001: 101 p.

Stülpnagel, R., A. Heinz, M.Kaltschmitt, and K. Scheffer. 2001. Annual crops from agriculture for energy generation; Comparison of different provision chains with respect to environmental and economic aspects. In *Proceedings of the 1st World Conference on Biomass for Energy and Industry,* S.Kyritsis et al. (Eds.),. 5-9 June 2000, Sevilla, Spain: 327-330.

Venturi, P., W. Huisman, and J.Molenaar. 1998. Mechanization and costs of primary production chains for *Miscanthus x giganteus* in the Netherlands. *Journal of Agricultural Engineering Research* 69: 209-215.

Venturi, P., and W. Huisman. 1998. Modeling the optimization of primary production costs of *Miscanthus*, in *Biomass for energy and industry*, 10th European conference and technology exhibition, Würzburg, 1998, Eds. H Kopetz et al, CARMEN, Rimpar, Germany, 806-809.

Werf, H.M.G. van der. 1994. *Crop physiology of fibre hemp* (*Cannabis sativa* L.) PhD Dissertation. Wageningen University, The Netherlands: 151p.