AN INTEGRATED APPROACH IN EVALUATION OF PRODUCTION OF ENERGY FROM BIOMASS

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ABSTRACT

It is predicted in the future a substantial proportion of the energy needs will be satisfied by energy from biomass. Growing energy crops such as sugar beet, sorghum or oil-seed rape at a large scale is then necessary. From a crop ecological point of view energy crops are only sustainable if they intercept large quantities of light, use this light in a efficient way, have a light harvest index of above-ground useable product, and do not require large inputs of energy, water, nutrients or chemical crop protectants to grow the crops or to store, transport and process their products. Both the quantity and quality must be high, predictable and stable. From an agronomic point of view it is essential that it is possible to grow such crops at large scale both within a specific rural area. This is only true if the energy crops fit in the crop rotation, the cropping and farming systems, and in the land use system. Moreover, energy crops need to be farmer friendly and profitable, and their cultivation needs to be supported by adequate plant breeding activities, seed supply systems, development of technical knowledge and agricultural tecnhology and long-term political support and market perspectives.

RÉSUMÉ

D'après les prévisions, à l'avenir, une partie remarquable des besoins d'énergie sera satisfaite par l'énergie fournie par la biomasse, ce qui impose la pratique sur grande échelle de cultures comme la betterave sucrière, le sorgho ou le colza. Du point de vue écologique-cultural, les cultures productrices d'énergie ne sont soutenables que si elles interceptent efficacement de grandes quantités de lumière, si elles utilisent efficacement cette lumière, si elles ont un indice d'interception de la lumière par les organes de la partie aérienne, et si elles ne requièrent pas d'apports importants d'énergie, d'eau, d'éléments nutritifs ou de produits phytosanitaires pour pratiquer les cultures ou stocker, transporter et transformer leurs produits. Il faut que la quantité et la qualité soient élevées, prévisibles et stables. Du point de vue agronomique, il doit être possible de pratiquer ces cultures sur grande échelle tant au niveau d'une exploitation agricole qu'à l'intérieur d'une région rurale donnée. Ceci n'est vrai que si les cultures productrices d'énergie s'adaptent à l'assolement des cultures, aux systèmes de culture et d'exploitation, ainsi qu'au système d'utilisation des terres. De plus, les cultures productrices d'énergie doivent être rentables et bien maîtrisées par les agriculteurs mais aussi supportées par des activités d'amélioration génétique, des systèmes d'approvisionnement des semences, le développement de connaissances techniques et de technologie agricole ainsi que par l'appui politique à long terme et les perspectives de marché.

Use of crops and crop products for non-food and non-feed use is an old phenomenon.

Especially fibre crops (flax, hemp), energy crops (trees, oil crops) and medicinal crops have been grown for centuries for such purposes.

Recent years have seen a huge resurgence in interest in industrial uses of crops and crop products due to the overproduction of agriculture in certain parts of the world, the commonly felt need to use renewable resources and their potential environmental benefits. These positive aspects of raw materials are also and perhaps particularly relevant for their use as biofuels.

A society that aims at true sustainability will mainly (or even merely) use recyclable or renewable material and energy resources.

At present, the increase in use of fossil resources for the production of energy and of petrochemicals is enormous.

Energy consumption will definitely continue to increase for long and at a high rate given the increasing demands by the developing economies, especially in Asia and South America. Therefore, a global society that is sustainable needs to develop large-scale alternatives for the use of fossil resources. There are many options and routes, but not all of them are politically feasible. One potential route is the use of biomass from crops.

This route is perhaps the most flexible and multifunctional one and therefore deserves careful consideration and study. Non-food use of plant products is not new, as stated above. Neither is the use of biomass for energy.

Biomass harvesting in order to use it for energy has been practised for thousands of years (stover, wood, camel dung).

Growing special energy crops for light and traction is also old. However, history clearly showed that with a rapid increase in per capita consumption of energy it is virtually impossible to rely on resources of vegetable origin only and societies quickly moved towards dependence on fossil energy sources.

It is now time to re-think this development and to invest in large scale, renewable and sustainable energy production instead of merely and quickly using the limited supplies available from biological processes in the past.

Often arguments in favour of biomass include the surmise that its production and use is environmentally sound. However, a sustainable society also demands sustainable technologies in all activities and this includes the production and use of biomass. Biomass production from agriculture must be sustainable in itself. This does not go without saying and proper life cycle analyses must confirm this assumption. Biomass may contain large quantities and concentrations of

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compounds (ash, water, contaminants) that need to be disposed of in a sustainable way, its production uses large quantities of scarce arable land, scarce water, scarce energy and other inputs, and its processing, use and waste management may not be so easy or efficient as for other resources. An ecologically and economically sound agriculture may be able to provide the raw material for a sustainable production and use of energy, but research and development on agronomic aspects of sustainable biomass production still have to go a long way.

This calls for a new approach, which is more flexible, cheaper and makes better use of the raw material. The normal procedure in the non-food production of agricultural raw materials has always been to grow a single crop for a single type of raw material, for example oilseed rape for biodiesel, or crambe for industrial oil. This approach hardly works for energy crops, especially not in areas with scarce (and therefore expensive) land. The new crop must then compete with other existing types of raw material, often in markets with low prices and low added values. This is only possible when the benefits of agricultural products are large or when the price/ performance ratio of the agricultural products is better. Benefits of use of agricultural products, however, are not always so obvious, especially not when used as basis of biofuel. The common argument that they are environmentally friendlier sometimes becomes doubtful when the entire life cycle is analysed. Often institutional barriers or lack of political support impede economic viability. The price/performance ratio is usually lower, due to lower and more variable quality of the agricultural raw material. Moreover, agricultural raw materials are often not flexible in their logistics and use.

However, new technologies allow us to design more flexible and cheaper systems of using raw biomass. The ideal is a multi-input/multi-output system. Such a system may use different raw materials (either waste, rest products, crop residues or crop products) and produces different types of products through a well-orchestrated chain of sophisticated processes, applying the latest available technologies. Especially integrated plant conversion by biocascading and the use of crop residues may be interesting options to optimise the use of raw material from agricultural origin.

The first interesting approach is to design such a chain of technological processes based on integrated plant conversion through biocascading. Integrated plant conversion uses all parts of the plant to synthesise a variety of products. Cascading means that the initial material is used to produce a highly valued product and that the waste of this process is further used for a next step in production yielding other products, etc. (multi-output). The final residue may be used for the production of energy. Such a system is multi-input since it may use different raw materials (either waste, rest products, crop

residues or crop products). The system is also multi-output since it produces different products through a well-orchestrated chain of sophisticated technological processes. Depending on the quality of the input the technological processes may be adjusted to change the proportions of the different outputs or to optimise the process in an economical sense. Residues or waste can be added in several phases of the biocascading process to increase the amount of material processed thus increasing the efficiency of the system.

Crop residue is interesting since it means using existing crops, technology and infrastructure. Moreover, as stated above, it may be part of an integrated system.

In this contribution we will focus on the use of arable crops for energy production. We will describe the agronomic aspects of non-food production for energy and the criteria for selection of potential crops especially suitable for such purposes. Agronomic criteria for selection of potential crops and for optimising their husbandry for biomass use are manifold and they relate to various aspects at crop level, farm level and regional and institutional level.

AGRONOMIC CRITERIA AND ASPECTS AT THE CROP LEVEL

Crop yield can be described by the following formula:

$$Y = LIGHT\ (INT) \times LUE \times HI$$

In which:

Y is the yield,

LIGHT (INT) is the total amount of light intercepted by the crop during the growing season,

LUE is the efficiency with which this light is converted into dry matter,

and HI is the harvest index.

The amount of light intercepted strongly depends on the synchrony between availability of light and the presence of green leaf area to intercept this light. Light

is a resource that needs immediate capture otherwise it is lost. Therefore LIGHT (INT) depends on weather (climate) and on the growth, development and senescence of the crop. For a large and prolonged interception of light a crop must start to develop early and rapid and must senesce late. These crop factors are usually influenced by so-called growth-determining factors (such as light, temperature, carbon dioxide). They determine the potential yield. Growth limiting factors (such as nutrients and water) are often in short supply in practice and therefore determine the attainable yield. Finally there are growth reducing factors (such as pests, diseases, weeds, pollutants) which reduce the green leaf area as well.

The light intercepted is used for basic processes of energy transfer and photosynthesis. There are three main pathways for photosynthesis in the plant kingdom. These differ in efficiency. The most efficient one is the so-called C4 path-way which is present in tropical crops such as maize, Miscanthus, sorghum and other crops that may serve as energy crops. Sugar beet, potato, and oil-seed rape have the less efficient C3 pathway, and are thus not able to profit from very high light intensities and do not grow so well under higher temperatures. A limited number of species (such as some halophytes, grown as an energy crop in ocean farming systems) have an even less efficient, third path-way (CAM-plants); they only open their stomata to absorb carbon dioxide during the night when transpiration is low. Within a certain path-way, the light use efficiency is relatively low, but fairly constant over time, over species and cultivars within species, at least under optimal conditions. Growth determining, limiting and reducing factors also affect light use efficiency. Negative effects are especially strong for drought, some diseases and pollutants.

HI is the harvest index, i.e. the proportion of the total biomass produced that is harvestable and useable. Especially in energy crops this index is often high. The harvest index is a reflection of crop development (ontology) and its ranges are dictated by species-specific responses to climate and weather.

Desired characteristics at the crop level include:

- high potential and actual yields of the crop (i.e. long crop cycle due to early start and late senescence resulting in a high and prolonged light interception; high light conversion efficiency, and thus preferably a C4 species) and of its most desired components (i.e. high harvest index);
- adequate yield security and stability (i.e. stress resistant and with a large compensation capacity);
- high and stable quality (high energy content, low content of polluting components, predictable in composition and behaviour);
- minimum input and maximum efficiency of resources (including water, fertiliser and chemicals for crop protection); this requires drought tolerance, high water and nutrient use efficiencies, resistance against pests, diseases and competitiveness against weeds; it also requires low nutrient contents (especially of nitrogen) in the plant parts to be used as biomass;
- minimum input of energy during cultivation, harvesting and on-farm processing. It should be possible to grow the crop with a minimum of soil tillage; therefore long cycle crops are preferred. Preferably the harvested plant parts should be above-ground. Root and tuber crops like sugar beet and potato may be interesting as an energy crop because they have prolonged light interception and very high harvest indices, but their harvestable organs are below ground and it requires considerable amounts of energy to lift and harvest these. If the crop stand needs to be cut, chopped, or ground, cultivars should be selected with relatively low resistance. The harvest product should also be dried (Miscanthus after a frost period) to avoid any additional costs of drying the biomass;
- environmentally friendly crop husbandry (e.g. little need of crop protection) and maximum contribution to carbon dioxide sequestration (efficient and long term fixation of carbon dioxide).

AGRONOMIC ASPECTS AND CRITERIA AT THE LEVEL OF THE FARM

When a crop has the potential to produce biomass in an efficient way, it still needs to be fit in a production system. In addition to economical feasibility, a farmer needs to take into account many tactical and strategic aspects when considering the suitability of a crop for his production system. Some of these include:

- the possibility to fit the crop in the current production, farming and land use systems (availability of labour, machinery, crop rotation, etc.);

– contribution to biodiversity;
– adequate potential acreage of the crop, i.e. the farming system should allow a considerable portion of the land to be cropped with the energy crop;
– farmer-friendly transport, storage, processing and use on the farm;
– low costs of production (such as costs of seeds, harvest, storage).

Agronomic aspects and criteria at the regional and institutional level

To profit from economies of scale and efficient logistics it is necessary that a large number of farmers within a certain region participate in the production of biofuel. To make that possible and attractive a myriad of agronomic and non-agronomic factors (both technological, economical and socio-political) play a role. We mention only the following :
– adequate potential acreage of the crop around centralised processing plants;
– potential of economical feasibility (adequate price/performance ratio);
– time for gradual growth to economies of scale and adequate added value;
– multiple use (for example through biocascading or through multi-input/multi-output systems);
– technological infrastructure for processing and use. This infrastructure can cope with the many suppliers, the possible high water contents and high biological activity of the raw material, and the large variation in its quality. The technology is partly available. Potential approaches are use of bio-oils, direct burning of biomass; pyrolysis, gas production, hydrothermal upgrading and other techniques;
– logistic infrastructure for transport, storage, processing and use is available;
– institutional and social changes (willingness to invest in alternative resources, depreciation of existing structures using petrochemicals is compensated, attitude) required for this switch in energy paradigm are stimulated;
– the market is accepting the new product and is appreciating its agricultural nature;
– adequate knowledge on the crop and its cultivation, availability of required inputs (such as selective herbicides) and advanced state of breeding and seed production systems;
– absence of critical problems in the cultivation and use of the crop or its products;
– political support for primary producers, processors and users (agricultural policy not only aiming at food production, but also at non-food objectives).

Agronomic opportunities: using genotype × environment × management interactions

There are significant interactions between genotype, environmental conditions and management (the so-called GEM interactions) in arable farming for energy production. Agronomists are expert in quantifying and manipulating these interactions. By doing so they can predict, assess or influence:
– the normal range of yields (based on variation in crop, cultivar and agronomy) and the potential biomass yield of different crops in different parts of Europe. This is relevant for the distribution of energy crops over Europe;
– the (range in) yield of the different plant components of specific crops in different parts of Europe, partly based on potential yield and on ontology and maturation;
– the (range in) quality of the different plant components;
– the economically optimal combination of components for each GEM situation;
– the stability of production of bio-mass of a certain composition;
– the resource-use efficiency during the production and processing.
As a consequence it is possible to quantitatively know:
– what quantities of different components may be produced in each country and at what cost;
– what potential qualities will become available;
– where which crop cultivars may best be grown;
– for what composition and quality farmers should aim in different parts of Europe;
– what kind of multi-output systems would be feasible (economically, socially and environmentally) in different regions of Europe.
Moreover, agronomists can manipulate quantities and qualities.

Perspectives and conclusion

New concepts require extensive research in which many actors and stakeholders are involved. This is especially true for growing and using biomass as raw material for large-scale energy production. It requires a new concept in technology, in farming and in multiple purpose land use, based on flexible inputs of biomass from efficient crops, crop residues and other wastes.
It will be necessary to concentrate the actual cultivation of energy crops in areas with cheap land and with the infrastructure to build and supply the biomass based power plants.
In this new concept of technology, the agronomic aspects of biomass production are often overlooked. More research is needed on the agronomy of energy crops to make their large-scale cultivation feasible. Moreover, a successful introduction of large-scale energy production from biomass requires a detailed strategy to make sure that primary production, processing and use develop hand-in-hand to the large scale dictated by the economies of scale. ●