ESTIMATING YIELDS OF BIOMASS CROPS IN THE NETHERLANDS

ODHAD VÝNOSŮ ROSTLINNÉ BIOMASY V NIZOZEMÍ

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ABSTRACT: The use of biomass crops as energy source is frequently mentioned as an option to reduce CO_2 emissions. For evaluation of the possibilities of using crops for energy supply it is vital to have reliable estimates of their yields. Candidate biomass crops like willow and miscanthus are not yet grown on a large scale, therefore it is difficult to assess their production. In this paper a simple method is developed to estimate regional averages of various biomass crops. The method is based on the linear relation between intercepted light and biomass production as found for most agricultural crops. A correction factor is introduced to account for the effects of various yield reduction factors. The quality of the yield estimations was studied by applying the method on several agricultural crops grown in two regions in the Netherlands. A deviation of less than 10% was found between actual and estimated yields. The estimated biomass yields in the Netherlands varied between 9–12 ton/ha and 11–14 ton/ha for the two regions respectively.

biomass crops; energy crops; yields; light use efficiency

ABSTRACT: Použití rostlinné biomasy jako zdroje energie se často uvádí jako prostředek, jak snížit emise oxidu uhličitého. Aby se mohly posoudit možnosti využití plodin k zisku energie, je potřebný spolehlivý odhad jejich výnosů. Reprezentanti těchto plodin, jako jsou vrba a miscanthus, se zatím nepěstují ve velkém, a proto je velmi obtížné hodnotit jejich produkci. V práci je popsána jednoduchá metoda určená k odhadu regionálních výnosů rostlinné biomasy u různých plodin. Je založena na lineárním vztahu mezi zachyceným světlem a produkcí biomasy, jak byl stanoven pro většinu zemědělských plodin (rovnice (1) až (3) a obr. 1). Různé vlivy snižující výnos jsou ve výpočtu respektovány prostřednictvím korekčního faktoru. Přesnost odhadu výnosu byla testována metodou používanou pro několik zemědělských plodin (viz tabulka v dodatku) pěstovaných ve dvou různých holandských regionech (obr. 2). Odchylky mezi skutečným výnosem a jeho odhadem byly menší než 10 %. Odhadnuté výnosy suché biomasy se v uvedených regionech pohybují v rozmezí 9 až 12 tun na hektar a 11 až 14 tun na hektar.

rostlinná biomasa; zisk energie; výnosy; účinnost světla

INTRODUCTION

The present use of fossil fuels as major energy source in the world implies that large quantities of CO_2 are emitted to the atmosphere. CO_2 is a greenhouse gas and increasing CO_2 levels in the atmosphere are likely to affect global climate. The IPCC report on global change (H o u g h t o n et al., 1990) estimated that under the „business as usual scenario“ (the present annual increase of CO_2 emissions is retained) the atmospheric CO_2 concentration will reach the 700 ppm level by the year 2050, which may have serious effects on global climate. One of the options to diminish CO_2 emissions in the use of so called energy crops. During growth crops capture CO_2 and when the crops are used for energy supply CO_2 is released again. This means that CO_2 is recycled. Through replacing a part the fossil fuels by energy from crops CO_2 emission can be reduced.

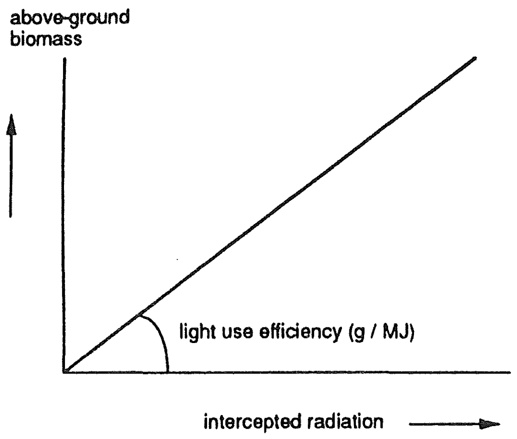
Recently several studies have been published on possibilities of growing energy crops in various regions of the world (L y s e n et al., 1992; H a l l et al., 1993). In these studies the expected yields of these crops determine the results of the evaluation. For agricultural crops like sugar beet or wheat, which can be used for ethanol production, yield data can be obtained from agricultural statistics. The yields of biomass crops (used for electricity production) are more difficult to determine. In the first place because rather unknown crops are suggested as options for biomass production, so that hardly any yield data are available. Secondly, because the yield of a crop is determined by growing conditions during its growing season, and since these conditions vary from one field to another and from one year to another, large variation in yields is observed. This implies that yields obtained in one region in one year cannot easily translated to yields in other regions or other years. These yield deferences are very large: the present average wheat yield the Netherlands is about 7 ton/ha, but individual farmers are harvesting 10–11 ton/ha in some years. In the third place, with respect to energy supply not the yield of one particular field is of interest but the amount of energy that can be produced for a whole region. This implies that the average yield in a region is required. This regionally average yield cannot be determined in field experiments.

In presently available evaluation studies on this subject the estimated yields are often based on a limited number of field experiments, and data are used for large areas (sometimes even globally). Since the yield in field experiments can deviate considerably from the regional average, and since expected yield is the key factor in most evaluation studies, improvement of the yield estimates can be a valuable contribution to the discussion on possibilities of using crops for energy production.

Here a very simple method is described to estimate regional yields of biomass crops. The method is based on knowledge obtained in agricultural research. The quality of the estimated yields is determined by applying the method to several agricultural crops from which regional averages are available. The regionally average yields of several biomass crops are estimated for two different regions in the Netherlands and results are compared to the yield estimates used in other studies on this subject.

METHOD

From research conducted with various agricultural crops is known that a linear relation exists between the amount intercepted solar radiation by the crop and the above-ground biomass produced (Monteith, 1977). The name „above-ground biomass“, which is used in literature, is confusing since it does include harvestable below ground plant material, like tubers of potato and root of sugar beet. The slope of the line is the so-called Light Use Efficiency (LUE, Fig. 1). The value of the LUE is determined by growing conditions of the crop, the value is lower under poor conditions and higher under good conditions. Under optimal conditions a value of 1.2–1.4 g/MJ of global radiation for the LUE is found for most C3 food crops, but also for fast growing trees (Monteith, 1977; Cannell, 1989). The value of 1.2–1.4 g/MJ is only applicable to crops that produce mainly carbohydrates, the production of other plant materials like proteins or oils requires much more energy (Penning de Vries et al., 1974). And a lower value for the light use efficiency must be used to calculate production of crops like sunflower or rapeseed. Candidate biomass crops don't produce these „energy expensive“ plant materials so that the 1.4 value is appropriate for estimation of their yields. The growth rate of C4 plants is higher than of C3 plants but only in warmer climates. In Dutch conditions values of



1. Relation between intercepted radiation and above-ground biomass produced

1.3 g/MJ were found for both maize and miscanthus (van der Werf et al., 1993). Here the value of 1.4 g/MJ is applied to all crops studied.

When the amount of radiation intercepted by a crop is known, the production of this crop under potential conditions can be calculated. The amount of intercepted radiation can be measured in field experiments, but it can also be derived from information on incoming radiation and development of the crop canopy. This latter option is used here. From most crops (even the rather unknown ones) some information can be found in literature on time of the year that leaves start to emerge, that closed canopy is formed that leaves are dropped or that crop is harvested. This information is used to determine the amount of radiation intercepted. It is assumed that a closed crop canopy captures all radiation and that in the period between leaf emergence and crop closure the fraction intercepted radiation increases linearly over time, and at the end of the growing season between start of leaffall and complete leaflessness the fraction decreases linearly over time (see scheme in appendix).

Multiplying the average daily incoming radiation, which can be obtained from climatic data sets, by the fraction intercepted during that day gives the intercepted radiation. Integration over the complete growing season results in the total amount of intercepted radiation in this period (I_{int}, in MJ/m^2). Multiplying by the value for LUE (1.4 g/MJ) results in the potential above-ground biomass (PAGB in g/m^2, dry matter) produced under optimal conditions

$$PAGB = I_{int} \times LUE \quad (1)$$

Generally not all total above-ground biomass can be used, the leaves of trees for instance remain in the field. The fraction of the total biomass that is finally harvested, is called the harvest index. For most crops the harvest index values can be found in literature. (Values used are given in the appendix.) Multiplying total above-ground biomass by the harvest index, on dry matter basis (HI) gives the obtainable yield (Y_p) in kg

2. Location of regions

1 – Flevopolder, 2 – Veenkoloniën

dry matter/ha. Factor 10 is introduced to recalculate from g/m^2 to kg/ha.

$$Y_p = \text{PAGB} \times \text{HI} \times 10 \quad (2)$$

The calculated yield is the production under optimal circumstances, in which crop yield is only determined by crop characteristics and climate. It is a measure of what is potentially possible under given conditions. The yields obtained in practice are generally much lower, due to a combination of water and nutrient shortages and damage done by pests and diseases. These effects could be eliminated by application of irrigation and fertilization and by crop protection measures. The ratio between actual and potential yield can be interpreted as characteristic for the type of agriculture in a region. In high input agriculture the ratio will be higher than in low input agriculture. Here this ratio will be called the Regional Yield Factor (RYF). The value of the RYF can be determined by using the above-described method for an agricultural crop from which yield data are available and divide actual yield through calculated yield:

$$\text{RYF} = \frac{Y_a}{Y_p} \quad (3)$$

in which: Y_a – the average regional yield in kg dry matter/ha

The actual yield data can be obtained from agricultural statistics. These yields are usually published as kg/ha fresh weight, for comparison with dry matter yields calculated here, recalculation is necessary. Data on the average moisture content of harvested plant material can be found in literature, values used are given in appendix.

Here the RYF is calculated for two regions in the Netherlands using yield data of potato: Flevopolder (region 1), this area reclaimed from the sea in the 1950s, with large farms on good soils and Veenkoloniën (region 2), with smaller farms on rather poor sandy soils (Fig. 2). In general yields in region 1 are higher than those in region 2.

The method was validated through comparison of actual yields of various agricultural crops and the estimated yields of these crops using crop data given in the appendix and the RYF determined from potato. Finally the yields of three candidate biomass crops, willow, poplar and miscanthus, were calculated using crop data given in the appendix. Multiplying the potential yield by the RYF leads to estimates of average regional yields of these crops in regions studied.

RESULTS

In the Netherlands potatoes are planted in April, crop emergence is around May 1st, and crop closure on June 20th, the crop is harvested in September (de Jong, 1985). Assuming a linear increase in the fraction intercepted light between May 1st and June 20th, an interception of all incoming radiation from June 20th to August 1st and a linear decrease in the fraction intercepted light between August 1st and September 15th, the total amount of intercepted light is 1429 MJ/m^2. Using equation 1 leads to a PAGB of 2 000 g/m^2. The harvest index of a potato crop is 0.75 so that a potato yield of 15.0 ton/ha (dry matter) can be obtained. In 1992 the average potato yield in region 1 was 53 ton/ha and in region 2 it was 43 ton/ha (fresh weight) (PAGV, 1993). Assuming a moisture content of 80% this means 10.6 and 8.6 ton/ha dry matter. Applying equation 3 results in a RYF for region 1 of 0.71 and for region 2 of 0.57.

The estimated and actual yields of three agricultural crops in the two regions in the Netherlands are given in Tab. I. In general the deviation between estimated and observed yield is small, only in one occasion the deviation was more than 10%. Estimated for the potential and actual yields of willow, poplar and miscanthus are given in Tab. II. The potential yield varied between 18 and 22 ton/ha for the different crops. The regional yields were lower.

DISCUSSION

REGIONAL YIELD FACTOR RYF

The average regional yield is affected by various factors, physical ones like climate and soil conditions but also by factors like knowledge of the farmers and infrastructure in the region (availability of irrigation water). Here the effects of all these different factors on the yield were not determined individually, only the overall effect on yield was derived by introducing the RYF. Climate and soil conditions remain more or less constant over the years, but the other factors change in time, so that the RYF is time dependent. In 1960, for instance, the average wheat yield in the Netherlands

I. Comparison between actual (Y_a) and estimated (Y_e) yields of three agricultural crops. The deviation (dev) between actual and estimated yield is expressed as percentage of the actual yield. Yields were estimated with the method described in the text, the regional yield factor (RYF) was obtained from potato yield data and was 0.71 for region 1 and 0.57 for region 2. Yields are expressed as ton/ha dry matter harvested material

Crop	Region 1			Region 2		
	Y_e	Y_a	dev	Y_e	Y_a	dev
Winter wheat	7.6	7.3	4%	6.1	5.4	13%
Sugar beet	15.1	15.4	2%	12.3	12.0	3%
Maize	14.6	15.4	5%	11.9	13.2	10%

II. The estimated potential yield and the regionally average yield of three biomass crops in the Netherlands in two regions. Yields are expressed as ton/ha dry matter harvested material

Crop	Potential yield	Regional yield	
		region 1	region 2
Miscanthus	21.9	15.3	12.3
Poplar	18.0	12.6	10.0
Willow	19.6	13.7	11.0

was 4.25 ton dm/ha leading to a RYF of only 0.39. When this value is used to determine potato yield in 1960 a value of 5.85 ton/ha is calculated which is in accordance with the average values for 1960 (5.68 ton/ha). Further increase of the RYF can be expected, but the value of 1.0 will never be reached since this would imply that in a whole region the production is optimal.

Besides a variation in time there is also a large spatial variation, which is shown in the difference of the RYF between the two regions studied. To prevent loss of information it is important to keep the size of the region studied limited, and use data of more or less homogeneous regions. It is theoretically possible to apply this method for the whole of Europe leading to an average European yield. But the usefulness of this value is very limited since the enormous variation occurs in yields within Europe (yields in Spain are only a quarter of yields in the Netherlands).

Due to the fact that regional average is affected by so many factors, yields of field experiments in the same region are usually above the average, simply because they are generally laid out on better soils and more measures are taken to prevent the occurrence of water and nutrient shortage or reduction through pests and diseases.

The application of the RYF on biomass crops implies that it is assumed that knowledge on how to grow such a crop is comparable to that of agricultural crops. For the potential biomass crops this is not yet the case. Simple agronomical information as what planting density is best, which varieties should be used in various regions, what are fertilizer requirements of the crop and what crop protection is needed, is lacking. So it is likely that the regional yields of these crops will be lower than calculated here.

VALIDATION OF THE CALCULATED YIELDS

Since there are no data on average regional yields of biomass crops the validation possibilities for the method are limited. The only available averages are those from the agricultural crops. As shown in Tab. I the deviation between estimated and observed yield of the agricultural crops is very small. This implies that the method described can be very useful for estimating yields. In one situation an overestimation of 13% was obtained (wheat in region 2). This difference in magnitude of the deviation can be understood by the fact that crops differ in their susceptibility to certain unfavourable conditions. Pests, for instance, are crop specific, yield reduction caused by an insect in potato cannot be extrapolated to wheat. When unfavourable conditions occur yield reduction is different for different crops. To eliminate this crop effect on RYF, it is preferable to determine the value of RYF for several crops and use the average value.

CALCULATED BIOMASS YIELDS

As shown in the appendix for all biomass crops studied a harvest index 0.7–0.75 is assumed. This implies that yield differences of these crops are the result of the different PAGB values are caused by differences in canopy development. Differences between the crops at the start of leaf emergence and leaf fall of about 2 weeks occur, which results in differences in PAGB of about 5 ton/ha. For agricultural crops like wheat, potato etc. the average crop emergence date and harvest date over several years are known, it is also observed that large differences between years occur. For the unknown biomass crops such average values are not available so that data from field experiments had to be used. Since large interannual variation can be expected, values found in one experiment can deviate from the average. Also large differences in canopy development between varieties occur. In the Netherlands a difference of one month in leaf emergence between early and late poplar clones is observed (van Haaren, 1987). Since it is not known which clone will be used for biomass production in the future, canopy development can deviate from values used here leading to other yields.

The above-mentioned uncertainties imply that given yield data for the biomass crops are only indicative. Therefore it cannot be concluded that miscanthus is the most promising biomass crop since there is too little crop specific information available. However, it can be concluded that the potential annual biomass production of 'a' perennial biomass crop lies between 18 and 22 ton/ha. Regional averages of these crops would be 13–15 ton/ha for the high yielding regions and 10–12 ton/ha for the low yielding regions in the Netherlands.

Biomass estimates given in literature for present conditions in temperate regions are 10–12 ton/ha

(Hall et al., 1993; Christersson et al., 1993) which agree with values found here. Estimates for yields in the near future (2000–2010) vary between 13–18 ton/ha (Lýsen et al., 1992; Christersson et al., 1993; Hall et al., 1993). Such yields imply a RYF value of at least 0.75 which is a reasonable value for the high yielding regions. For the less favourable regions it is rather unlikely that the present RYF of 0.57 would increase up to 0.75 within 10 years. For the distant future (2 030) values of over 20 ton/ha are mentioned (Okken et al., 1994), these values are even higher than the annual potential production. Further it is unlikely that RYF of 1.0 can be achieved future. On individual fields potential production may be possible but over large growth limitations like water shortage will remain so that RYF will stay lower than 1.

CONCLUSIONS

Based on the fact that yields of agricultural crops are estimated with an inaccuracy of less than 10%, it is concluded that the estimation method described in this paper can be a useful tool in the research to possibilities using biomass crops for energy supply. Biomass crops in the Netherlands will yield about 10–12 ton/ha in present conditions. The estimates for future biomass yields used in recent studies are higher than can be expected on the basis of this method.

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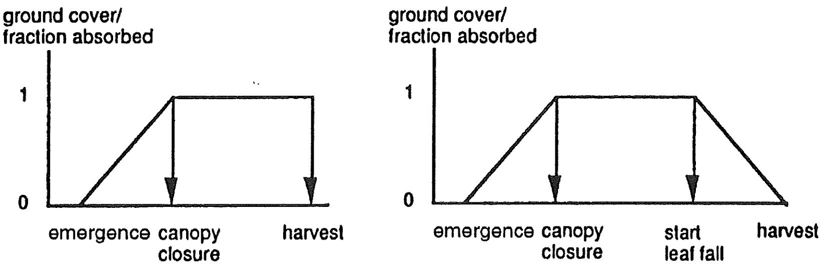
APPENDIX

CROP	Growing season	Canopy	Develop-ment PAGB	H. I.	Potential yield moisture content	Remainder moisture content	References
Winter wheat	A, Nov-Sept	1IV, 15V, 1VIII, 15VIII	24	0.45 grains	10.8 15%	8.8 straw 15%	Jong de, 1986
Potatoes	A, Apr-Sept/Oct	1V, 20VI, 1VIII, 15IX	20	0.75 potatoes	15.0 80%	5 leaf, stems 90%	Jong de, 1985a; Stol et al., 1991
Sugar beet	A, 15 Apr, Nov	1V, 20VI, 1XI	27	0.8 beet	21.6 77%	1.1 leaf, tops 87%	PAGV, 1986
Maize (silage)	A, May-Nov	15V, 20VII, 1XI	22	0.95 all	20.9 73%	stubble remains	Jong de, 1985b
Miscanthus	P, 15 Apr-Nov	15IV, 15VI, 1XI	30	0.73 stems	21.9 20%	leaves remain in field	Werf van der et al., 1993
Poplar	P, Apr-Oct	1V, 15VI, 15IX, 15X	25	0.72 stem, branches	18.0 50%	leaves remain in field	Kolster, 1982; Cannell et al., 1988
Willow	P, 15 Apr-Nov	15IV, 10VI, 1X, 1XI	28	0.70 stem, branches	19.6 50%	leaves remain in field	Nilson, Eckersten, 1983; Cannell et al., 1987

EXPLANATION OF CATEGORY NAMES USED IN APPENDIX

Growing season: period between sowing and harvest for annuals (A) and period between leaf emergence and leaf fall (poplar, willow) or annual dying (miscanthus) of the perennials (P).

Canopy development
1IV = April 1st, 15V = May 15th
3 data: leaf emergence, closed canopy, harvest
4 data: leaf emergence, closed canopy, start of leaf fall, harvest



PAGB: potential above-ground biomass expressed in ton dry matter/ha. Value is obtained through multiplying intercepted radiation by light use efficiency of 1.4 g/MJ.

Harvest index (H. I.): the fraction of the above-ground biomass that is harvested, the plant organs harvested are mentioned.

Potential yield: potential yield of the crop based on PAGB and the harvest index. Yield is expressed in ton/ha dry matter. In agricultural statistics the yields are given as fresh weight, moisture content of harvested organs is therefore given.

Remainder: this is the part of the crop that does not belong to the yield. In some cases the remainder can be used for other purposes (for instance the straw of the wheat plant) in those cases the production (in ton/ha dry matter) and moisture content is given.

References: the literature used to obtain information on canopy development, harvest index, moisture content etc. for each crop.

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