The energetic evaluation of technologies for fuel preparation from grass plants

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Abstract. The technologies of growing, harvesting and preparing for fuel traditional feed type grasses (the mix of cereal and legume grasses) and coarse-stemmed vegetative plants (topinambours and sunflowers) were evaluated and a rational technique was selected. The methods of energetic evaluation of fuel preparation technologies were reviewed.

After energetic evaluation of the technologies it was estimated that the total energy input of growing and harvesting grasses and legumes was equal to 8334 MJ ha^{-1}, topinambour stems – 14378 MJ ha^{-1} and sunflower stems – 11324 MJ ha^{-1} respectively. The total energy input of growing and harvesting of traditional grasses was by 72% lower than that of topinambour stems and by 36% lower than the energy input required for fuel production from sunflower stems. From an energetic perspective, the technology of fuel preparation from traditional grasses is more advantageous than the technologies of fuel preparation from coarse-stemmed plants, specifically topinambour and sunflower stems.

Key words: traditional grasses, topinambours, sunflowers, stems, fuel, technology energy evaluation, energy input

INTRODUCTION

To harvest the biomass of traditional grass plants used for forage and fuel preparation the same technologies and machinery are applied as in managing forage grasses and straw. The grass used as fuel, as in forage production, has to be cut, dried to 17–20% moisture content, pressed into round or rectangular bales and stored in a covered storage area (Žaltauskas, 2002; Jasinskas & Liubarskis, 2003; Jasinskas et al., 2003). It is expedient to compare and evaluate this technology, choose suitable machinery and carry out energy evaluation of this technology.

Several technological variants (Jasinskas & Sakalauskas, 2003) common abroad can be used for harvesting and producing coarse-stemmed grass plants for fuel:

- Plant stems are cut by a motor reaper in late autumn, baled and kept in a barn. The stems that have dried to 20% of moisture content are chopped by stationary drum or disk choppers and the chaff is burnt in special furnaces.
- The stems of coarse-stemmed grass plants are left to dry in the field until they reach 20–25% moisture content or are cut in early spring by maize harvesters; the chopped mass is loaded into car or tractor trailers, transported to storage and burnt in special furnaces.

In practice, the latter technological variant is expedient to use as manual work is minimal-and all technological operations can be fully mechanized.

Work objectives are the evaluation of technologies for growing, harvesting and fuel production from grass plants, selection of machinery and energy evaluation of harvesting and fuel preparation technologies of coarse-stemmed grass plants.

REVIEW OF ENERGY EVALUATION METHODS OF TECHNOLOGIES

Generally, energy input per area unit is calculated when carrying out energetic evaluation of technologies. When grass plants are prepared for forage or fuel, a simplified energetic evaluation of production technologies is used (Scholz et al., 2001; Sirvydis, 2001; Jasinskas & Sakalauskas, 2003). When calculating energy input by this method, the energy input of human labour for production operations and the energy input used for machinery manufacture are not taken into account. We assume that

$$E_i = E_o + E_1, \tag{1}$$

where: E_i – energy input for solid fuel production, MJ ha^{-1};
E_o – direct energy input (fuel used, electric power, heat), MJ ha^{-1};
E_1 – indirect energy input (fertilizers, herbicides, seeds, etc.), MJ ha^{-1}.

Direct energy input is calculated as follows:

$$E_o = G_f \cdot k_f + G_e \cdot k_e + G_h \cdot k_h, \tag{2}$$

where: G_f, G_e, G_h – fuel, kg ha^{-1}, electric power, kWh ha^{-1}, heat, MJ ha^{-1}, input;
k_f, k_e, k_h – coefficients of recalculation of energy input into MJ.

In calculation the following values are used:
k_f = 42,7 MJ kg^{-1}; k_e = 3,6 MJ $kW \cdot h^{-1}$; k_h = 0,00419 MJ $kcal^{-1}$.

Fuel consumption for different operations of grass plant preparation is given (Sirvydis, 2001) in which the summarized research data from machinery testing stations and other institutions are presented. In establishing energy input for a technology, energy input according to different operations is summed up.

Indirect energy input when using fertilizers and other chemicals is calculated as follows:

$$E_1 = \frac{\gamma \cdot G_p}{T_o}, \tag{3}$$

where: E_1 - indirect energy input, MJ ha^{-1};
G_p - rate of incorporation of fertilizers and chemicals, kg ha^{-1};
γ - energy equivalent of production, MJ kg^{-1};
T_o - duration of production actions, years.

The amounts of active matter and energy equivalents of some fertilizers are given in (Sirvydis, 2001).

In making a more accurate energetic evaluation of technologies, energy input of machinery manufacturing and human labour energy input are evaluated additionally for individual technological operations (Methodological recommendations..., 1989; Strakšas, 2002). Tariffs of mechanized operations, fuel consumption, efficiency of aggregates and human labour input are calculated according to the newest data (Tariffs of mechanized …, 2003).

An analogous methodology of energy evaluation of the technologies of grass plants used as fuel is used in our work as well: direct and indirect energy input (2) and (3) equations, energy input of the machinery used and human labour energy input (calculations are recorded in the Methodological recommendations..., 1989) are evaluated.

The energy accumulated in the production of energy plants is evaluated by establishing their calorific capacity during incineration (Sirvydis, 2001; Scholz et al., 2001). The research showed that the calorific value of grass plants was equal to that of straw and the lower burning heat value of combustible mass was 17.0–17.6 MJ kg^{-1}. Burning temperature of grasses and their mixtures in the furnace was 740–750°C; the temperature of topinambours and sunflowers was 680–700°C (Žaltauskas, 2002; Jasinskas & Sakalauskas, 2003). After establishing plant yield (kg ha^{-1}) and their calorific value (MJ kg^{-1}) it is possible to calculate the energy accumulated in production (MJ ha^{-1}).

MATERIALS AND METHODS

In 2003 in the experimental base of the Lithuanian Institute of Agricultural Engineering and Lithuanian Institute of Agriculture, energy plants – traditional grass plants used for forage (mixture of grasses and legumes) and coarse-stemmed grass plants - topinambours (*Helianthus tuberosus* L.) and sunflowers (*Helianthus* L.) - were analysed: harvesting, handling and preparation for fuel technologies were assessed and machinery selected. In qualitatively evaluating technologies fuel preparation losses occurring during handling, loading and transporting the plants were established (Sirvydis, 2001). Energetic evaluation of technologies was carried out according to the described standard methodology (Methodological recommendations..., 1989; Sirvydis, 2001; Strakšas, 2002; Jasinskas & Sakalauskas, 2003; Tariffs of mechanized …, 2003). In evaluating technological operations for plant growing, harvesting and fuel preparation, the following indicators of energy evaluation were calculated:

- Direct energy input;
- Indirect energy input;
- Energy input of machinery manufacturing;
- Energy input of human labour.

By summing up these indicators the total energy input of fuel production from one hectare (MJ ha^{-1}) is found. The calculated total energy input of individual technologies (of traditional grasses and coarse-stemmed grass plants) was estimated and energy input percentage of plant growing and harvesting was assessed. The accuracy of energy input estimation is 1 MJ ha^{-1} and the calculation is 0.1 MJ ha^{-1}.

RESULTS AND DISCUSSION

Technology of fuel preparation from traditional grasses

During qualitative evaluation of the technology the losses of handling grass plants used for fuel in the field (grass turning, collecting, pressing into round bales and transporting to storage) were established. In accordance with the research results, these losses were equal to 10–12% and they were taken into account during the energy evaluation of the technology when selecting plant productivity (Sirvydis, 2001).

In energetic evaluation of the technology it is suggested to use a technology and machinery of fuel preparation employed in traditional forage grasses, as presented in Table 1.

The following fuel preparation technology and machinery are proposed: Grasses are cut by rotary mower KRN-2.1; the mass is turned and raked into windrows by a rotary rake tedder GVR-6. In favourable dry weather, after 5 or 6 days the grass dries up to 20% and is pressed into round bales by a press PRP-1.6.

The round bales are loaded onto tractor trailer 2PTS-4 by a loader PF-0.5 and transported to storage (transporting distance is up to 5 km) and then unloaded by the same loader. Hay barns, or any roofed building, are suitable for storing the bales or they can be stored in stacks covered with polyethylene film. The storage place must be dry, protected from surface and ground waters.

Indirect energy input for fertilizers and seeds (for technological operations 3,5 and 4 in Table 1) is assessed (Sirvydis, 2001):

1) Distribution of fertilizers: fertilizer – double super-phosphate - 300 kg × 6.4 = 1920 MJ ha^{-1};
2) Distribution of fertilizers: fertilizer – potassium chloride - 200 kg × 5.3 = 1060 MJ ha^{-1};
3) Sowing together with harrowing: seeds – mixture of grasses+legumes (reed canary grass+ lupin) - 25 kg × 7 = 175 MJ ha^{-1}.

Total energy input for fertilizers and seeds: is 3155 MJ ha^{-1}.

Energy input (fertilizer and seed included): 3761.3+3155.0=6916.3 MJ ha^{-1} of which: growing + fertilizers, seed = 4088.0 MJ ha^{-1}; harvesting = 2828.3 MJ ha^{-1}.

Table 1. Direct energy input of growing and harvesting mixes of cereal and legume grasses.

Description of jobs	Composition of aggregate (tractor + implement)	Actual productivity, ha h^{-1}	Fuel consumption, kg ha^{-1}	Energy input, MJ ha^{-1}
1. Ploughing	MTZ-82+PN-3-35	0.7	13.5	575.6
2. Cultivation	MTZ-82+KRN-4.2	1.9	5.1	217.8
3. Distribution of fertilizers	T-25+TB-0.5	4.0	1.4	59.8
4. Sowing together with harrowing	MTZ-80+SZP-3.6+ BZSS-1.0 (X4)	1.21	5.0x4	20.0
5. Distribution of fertilizers	T-25+TB-0.5	4.0	1.4	59.8
				Σ =933.0
6. Grass cutting	MTZ-80+KRN-2.1	1.4	4.6	196.4
7. Grass turning	(MTZ-80+GVR-6) x2	3.2x2=6.4	2.5x2 =5.0	213.5
8. Grass raking into windrows	MTZ-80+GVR-6	3.2	2.5	106.7
9. Grass collecting and pressing	MTZ-80+PRP-1.6	0.7	5.5	234.8
10. Round bale loading	MTZ-80+PF-0.5	0.5	8.0	341.6
11. Round bale transporting	MTZ-80+2PTS-4	0.2	32.6	1393.7
12. Round bale loading into storage area	MTZ-80+PF-0.5	0.5	8.0	341.6
				Σ =2828.3
			Total:	**3761.3**

Notes: 1) recalculation of diesel (Fuel consumption, kg) into Energy input, MJ coefficient: k_k=42.7 MJ kg^{-1} (Sirvydis, 2001);
2) grass productivity – 8 t ha^{-1} DM (we calculate it as the 1^{st} harvest; usually there are 2-3 harvests of 2-4 t ha^{-1} DM each);
3) calculated for grasses – reed canary grass with perennial lupin.

The total energy input is calculated for the proposed technology (after assessing energy input of machinery manufacturing and human labour) and presented in Table 2.

From the data presented in the table we can see that the total energy input of growing traditional grasses and fuel preparation reaches 8334 MJ ha^{-1}. The greatest percentage of energy input (about 83%) is made up of direct and indirect energy input. The energy accumulated in the production reaches up to 140 GJ ha^{-1} and it is about 16 times greater than energy input for fuel preparation.

In the calculations, energy input of storing plants prepared for fuel is not taken into account as it is similar for all technologies compared.

Table 2. Energy input of growing and harvesting mixes of cereal and legume grasses (the summary of energetic indexes).

Titles of indexes ant measuring units	Energy input of growing	Energy input of harvesting	Total energy input
Direct energy input, MJ ha^{-1}	933.0	2828.3	3761.3
Indirect energy input (fertilizer, seed), MJ ha^{-1}	3155.0	-	3155.0
Energy input of machinery manufacturing, MJ ha^{-1}	412.2	984.7	1396.9
Energy input of man labour, MJ ha^{-1}	4.0	17.1	21.2
Total energy input, MJ ha^{-1}	4504.2	3830.1	**8334.3**
The energy accumulated in the production, GJ ha^{-1}			to **140**

Technologies of fuel preparation from topinambours and sunflower stems

When evaluating energy of the technology of fuel preparation from topinambours, the machinery for individual technological operations is suggested in Table 3, in which direct energy input of growing and harvesting of topinambours is calculated.

Table 3. Direct energy input of growing and harvesting the topinambour stems.

Description of jobs	Composition of aggregate (tractor + implement)	Actual productivity, ha h^{-1}	Fuel consumption, kg ha^{-1}	Energy input, MJ ha^{-1}
1. Digging and collection of tubers	MTZ-82+ KTN-2B	0.4	14.6	623.4
2. Soil ploughing	MTZ-82+ PN-3-35	0.7	13.5	575.6
3. Continuous soil cultivation	MTZ-82+ KRN-4.2	1.9	5.1	217.8
4. Tubers planting	MTZ-82+ Cramer	0.7	8.0	341.6
5. Distribution of fertilizers	T-25+TB-0.5	4.0	1.4	59.8
6. Interlinear cultivation	MTZ-80+ KON-2.8PM	0.9	6.0	256.2
				Σ =2074.4
7. Stems cutting, chopping	E-281 C	1.3	12.2	520.9
8. Chopped stems transporting	MTZ-80+ 2PTS-4	0.2	32.6	1393.7
9. Chopped stems loading into storage place	MTZ-80+ PKU-0.8A	0.5	8.0	341.6
				Σ =2256.2
			Total:	**4330.6**

Note: topinambour stems productivity is 10 t ha^{-1} DM.

The following machinery is used to harvest and handle the plants: the stems are cut and chopped by self-propelled forage harvester E-281C, which loads the chopped mass to tractor trailer 2PTS-4. The chaff is transported and unloaded in a storage area (transporting distance is up to 5 km). The mass is loaded into special containers or piles by loader PKU-0.8A and stored until it is burned.

Indirect energy input for fertilizers and seeds are assessed:

1) Distribution of fertilizers (fertilizer-saltpetre)-300 kg ×27.6 = 5520 MJ ha^{-1};

2) Planting of topinambour tubers: 800 kg × 3.0 = 2400 MJ ha^{-1}.

Total: 7920 MJ ha^{-1}.

Total energy costs (fertilizer and seeds): 4330.6+7920 =12250.6 MJ ha^{-1}

of which: growing + fertilizers, seeds = 9994.4 MJ ha^{-1};

harvesting = 2256.2 MJ ha^{-1}.

The summary of the total energy input for the proposed technology (after assessing energy input of machinery manufacturing and human labour) is given in Table 4.

Table 4. Energy input of growing and harvesting of topinambour stems (the summary of energetic indexes).

Description of indexes ant measuring units	Energy input of growing	Energy input of harvesting	Total energy input
Direct energy input, MJ ha^{-1}	2074.4	2256.2	4330.6
Indirect energy input (fertilizer, seed), MJ ha^{-1}	7920.0	-	7920.0
Energy input of machinery manufacturing, MJ ha^{-1}	1193.2	914.4	2107.6
Energy input of man labour, MJ ha^{-1}	9.0	10.9	20.0
Total energy input, MJ ha^{-1}	11156.7	3181.5	**14378.2**
The energy accumulated in the production, GJ ha^{-1}			to **170**

The total energy input of topinambour stems growing and harvesting is equal to 14378 MJ ha^{-1}. Direct energy input (including indirect energy input for fertilizer and seeds) represents the greatest percentage of energy input (about 85%). The energy accumulated in the production reaches up to 170 GJ ha^{-1} and it is about 12 times greater than energy input for fuel preparation. The achieved total energy input of growing topinambours and biofuel production is by 72% greater than energy input required to prepare fuel from traditional grasses.

The stems of coarse-stemmed plants can be harvested and chopped in late autumn or winter when mass moisture decreases to 50%. Such chaff is expedient to use in boiler-houses of large capacity with a chamber for intensive fuel combustion. Drier fuel of 20-25% moisture content is recommended for use by owners of individual houses with boilers of limited capacity.

In order to ensure chaff burning efficiency it is recommended to harvest the stems early in spring after they have dried in the field and when the ground is still frozen. The uncut stems kept outside until spring dry naturally and reach 20–25% of moisture content; there is no need to dry them additionally. However, if topinambour stems are kept in the field for a very long time, their biological losses increase – in spring the plants lose 8–10% of dry matter.

In qualitatively evaluating this technology mechanical losses were identified at handling (chopping, loading to a trailer, transporting and unloading in a storage area) topinambour stems, resulting in a 4–5% loss. When stems are harvested and handled in spring after evaluation of biological dry matter losses, the total losses reach 12–15% (similar to sunflower stem losses).

Similar technology and machinery as that used for topinambours is used to grow sunflowers, harvest and handle their stems (instead of digging and sowing of topinambour tubers the sunflower seeds were drilled by a drill SZ-3.6). The total energy input of sunflower stem growing and harvesting is presented in Table 5.

Table 5. Energy input of growing and harvesting of sunflower stems (the summary of energy indexes).

Titles of indexes ant measuring units	Energy input of growing	Energy input of harvesting	Total energy input
Direct energy input, MJ ha^{-1}	1301.5	2256.2	3557.7
Indirect energy input (fertilizer, seed), MJ ha^{-1}	6360	-	6360
Energy input of machinery manufacturing, MJ ha^{-1}	476.2	914.4	1390.6
Energy input of man labour, MJ ha^{-1}	4.8	10.9	15.8
Total energy input, MJ ha^{-1}	8142.5	3181.5	**11324.0**
The energy accumulated in the production, GJ ha^{-1}			to **150**

The total energy input of sunflower stem growing and harvesting is equal to 11324 MJ ha^{-1}. The greatest percentage of energy input (about 88%) is comprised of direct energy input (including indirect energy input for fertilizer and seed). The energy accumulated in the production reaches 150 GJ ha^{-1} and is about 13 times greater than the energy input for fuel preparation.

Research established that the total energy input of growing and harvesting traditional grasses is by 72 % lower than that of topinambour stems and by 36 % lower than the energy input required for fuel preparation from sunflower stems. The energy input of growing and harvesting different kinds of plants used as a fuel is presented in Fig. 1.

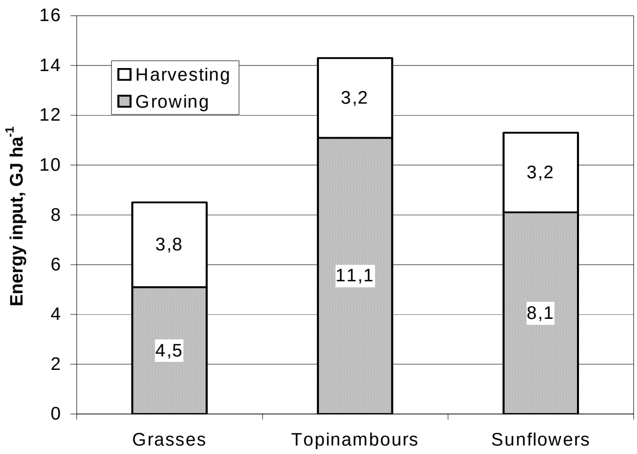

Fig. 1. Energy input of growing and harvesting energy plants.

The chart in Figure 1 shows that the least difference of energy input for plant growing and harvesting is that of grasses (4.5 GJ ha^{-1} used for growing, 3.8 GJ ha^{-1} - for harvesting) and the greatest is that of topinambours (actually 11.1 GJ ha^{-1} are used for growing and 3.2 GJ ha^{-1} - for harvesting). Finally, it can be stated that energetic evaluation of the technology of fuel preparation from traditional grasses is more advantageous than the technologies of fuel preparation from coarse-stemmed plants – topinambour and sunflower stems. If energy ratios were compared, for grass this ratio was 16.4, for topinambours 11.8 and for sunflower it was 13.2.

CONCLUSIONS

During qualitative evaluation of the technologies of fuel production from grass plants the established losses of plant harvesting and handling production were 10–15%. These yield losses were taken into account while carrying out energy evaluation of technologies. After energetic evaluation of technologies it was established that the total energy input of growing and harvesting of grasses and legumes was equal to 8334 MJ ha^{-1}, topinambour stems – 14378 MJ ha^{-1} and sunflower stems – 11324 MJ ha^{-1} respectively. The total energy input of growing and harvesting traditional grasses was by 72% lower than that of topinambour stems and by 36% lower than energy input required for fuel production from sunflower stems. If energy ratios were compared, for grass this ratio was 16.4, for topinambour,11.8, and for sunflower, 13.2. From the energy perspective the technology of fuel production from traditional grasses is more advantageous than the technologies of fuel preparation from the coarse-stemmed plants topinambour and sunflower stems.

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