BIOMASS POTENTIAL OF PLANTS GROWN FOR BIOENERGY PRODUCTION

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Abstract
In 2010 and 2011, we established the biomass potential of 14 grass species and 3 tree species grown for bioenergy purposes. The tested plants were divided into groups. In the imported plants' group, the highest dry matter yield (9.58 t ha^{-1}) was produced by *Sida hermaphrodita* when cut once. Other plants of this group were less productive: dry biomass yield of *Silphium perfoliatum* was 7.29 t ha^{-1}, of *Polygonum japonica, Polygonum sachalinensis* 8.74-5.13 t ha^{-1}, respectively. Due to the cold and snowy two winters, *Miscanthus giganteum* three-four year old stand severely thinned out and the yield declined to 7.14 t ha^{-1}, at N_{60-120} kg ha^{-1} fertilization level. Of the non-traditional plants, the highest biomass content was accumulated by *Artemisia dubia* (11.10 t ha^{-1}) and *Helianthus tuberosus* (8.56 t ha^{-1}), *Artemisia dubia* biomass was 3.3 times as high as that of *Artemisia vulgaris*. In the group of local plants, unfertilized *Galega orientalis* produced 10.98 t ha^{-1} dry biomass over 3 cuts. N_{120} kg ha^{-1} –applied *Phalaris arundinacea* produced 9.89 t ha^{-1}. Other legumes, *Medicago sativa and Onobrychis viciifolia,* in the sowing year and first year of use produced little biomass 6.16-5.21 t ha^{-1}.
Forest plants were cut in the autumn of 2010 after 3 growing seasons (2008-2010). The largest amount of dry biomass was produced by *Salix viminalis* 32.7-38.1 t ha^{-1} and *Populus nigra* 24.0-33.0 t ha^{-1}. When forest plants were grown in arable land, nitrogen fertilization had little effect on biomass yield, a biomass reduction trend was observed at N_{120} kg/ha fertilization. *Salix viminalis* had also low nitrogen and sulphur contents. *Salix viminalis* was best suited for combustion.
Key words: biomass, productivity, fertilization, bioenergy, tolerance.

Introduction

One of the renewable energy resources is plant biomass. In terms of moisture, our climate is favourable for most plants - the sums of active temperatures vary on average from 2000 to 2250°C. As a result, not only indigenous *Poacea* family's C_3 plants but also imported C_4 type plants, possessing very high energy potential, are a promising material for bioenergy production. Up till now, imported plants (*Sida hermaphrodita*, *Polygonum japonica, Polygonum sachalinensis ,Miscanthus giganteum*) have been encountered as single specimens or in groups but only as ornamental plants. There is little research done in Lithuania into the choice and cultivation of plants designed for energy needs. Willows of some local flora and introduced *Salix* L. taxa have been comprehensively researched at the Institute of Botany by D. Smaliukas. His research evidence suggests that the yield of air-dry above-ground stem biomass of the six-year-old plantations was 45-55 t ha^{-1}. Willow trees grown on light soils produced an annual biomass yield of 5.60 t ha^{-1} over the first three years of cultivation. (Smaliukas, 1996). At the Institute of Agriculture, in Dotnuva, the yield of dry biomass of perennial tall grasses amounted to 6–9 t ha^{-1} and only in favourable years it amounted to up to 12 t ha^{-1} (Kryževičienė, 2006; Jasinskas at al., 2008). Continuing the search for potential energy crops and expecting that the global climate change processes and climate warming will become conducive to warmth-loving C_4 type plants, we chose *Miscanthus* hybrid as a research object, which had been tested under field conditions in Lithuania. Research done in the USA and Europe in various climate zones, soils and regions over the last 20 years has proved *Miscanthus* to be a plant possessing one of the highest energy biomass potentials (Clifton-Brown et al., 2004; Heaton et al., 2008). The advantage of *Miscanthus* over other energy plants is undoubted in many countries of warmer climate zones; however, research evidence obtained in the cooler climate zones is rather diverse. The summarised results of tests done on 15 *Miscanthus* genotypes in Sweden, Denmark, England, Germany and Portugal suggest that the biomass yield is increasing with every year of cultivation from 2 t ha^{-1} in the first year to 9–18 t ha^{-1} in the second and third years. The green biomass of individual hybrid lines totalled from 29 to 40.9 t ha^{-1} (Clifton-Brown et al., 2001). It has also been noted that the genotypes that yielded better in cooler climate zones were less productive in warm climate zones. In the countries with a cooler climate, the spread of *Miscanthus* species is constrained by its susceptibility to contrasting, especially to low temperatures, and by the fact that the plants do not ripen seed (Lewandowski et al., 2000). In Lithuania, plants are often damaged by late frosts in spring and cooccurring soil droughts and hot weather spells. As a result, research on *Miscanthus* adaptivity in specific conditions is indispensable.

In Poland, our neighbouring country, *Miscanthus, Sida hermaphrodita* and 7 *Salix* genotypes were grown for energy purposes in alluvial humus-rich and alluvial sandy soils. Of all the tested plants, *Salix viminalis* was proved to be the most productive one. On more fertile soils its biomass yield in 2001-2004 was 10.1 t ha^{-1} DM, in different soils biomass yield varied from 7 to 13 t ha^{-1} DM (Nalborczyk 2005; Szczukowski et al.2006)

The search for and development of renewable energy sources in Lithuania as well as rational use of their resources is becoming increasingly relevant. The study was aimed to explore growth and development peculiarities of the perennial plants differing in origin, type and species and to estimate biomass yield as influenced by various nitrogen fertilization.

Materials and methods

The trials were conducted in Dotnuva (lat. 55º 24′ N, 23º 52′ E), in a reclaimed river bed territory. The soil is light, sand on sand with small stone and gravel admixture, *Eutri-Cambic Arenosols* (*ARb-eu*). The soil chosen for these experiments is less suited for other plants. It is neutral, deeper alkaline, with a humus status of 2%, with moderate total nitrogen, available phosphorus and potassium contents .The pre-crop was red clover of the third year of use. Early in spring, the clover field was ploughed; the soil was prepared for planting by a cultivator and a harrow. A plantation of energy plants was established in 2007. Four groups of energy plants were investigated: group 1- short rotation forest plants - *Salix viminalis* L., *Populus tremula x P. tremuloides* and *Populus nigra* L., group 2- imported herbaceous plants - *Miscanthus* x *giganteus*, *Sida hermaphrodita*, *Silphium perfoliatum* L., *Polygonum sachalinensis* L., *Polygonum japonica* hybrid, group 3- non-traditional plants – *Artemisia vulgaris* L., *Artemisia dubia* Wall., *Helianthus tuberosus* L.), *Panicum virgatum* L. and group 4 - indigenous (local) plants as a control – *Dactylis glomerata* L., *Phalaris arundinacea* L., *Galega orientalis* Lam., *Medicago sativa* L. *Onobrychis viciifolia* L.

Salix viminalis were planted in beds with inter-row distances of 0.75 m and 1.5 between double beds. The distances between plants in rows were 0.5 m. A total of 16 000 plants were planted per hectare. *Populus* of both species was planted at a density of 1 plant per square meter, 10 000 plants per hectare. Imported plants *Polygonum* and *Silphium* were planted at a density of 1 plant per square meter, 10000 plants per hectare. The seedlings of the *Miscanthus* hybrid were obtained from Austria. They were grown up to 2–4 leaves using the vegetative propagation method – chopped rhizomes. Two plants were planted per square meter, 20 thousand plants per hectare. *Sida* crop was established by planting 2 plants per square meter in rows with inter-row spacing of 1m. *Artemisia vulgaris* planting material was collected from the adjacent crop rotation stands. *Artemisia dubia* was planted using the vegetative propagation method – chopped rhizomes. *Helianthus* was planted by tubers - 2 tubers per square meter, 20000 seedlings per hectare with 1 m inter-row spacing. Indigenous (local) plants – perennial grasses were sown by a drill with 15 cm inter-row spacing. The experiment was designed as a randomized complete block with three replicates. Plot size was 10x10m. Harvested plot size - $10m^2$.

$P_{60}K_{60}$ fertilization was applied on all the area before planting. In the first year, N_{60} was applied as a started to stimulate growth. In the second year, nitrogen fertilization scheme N_0, N_{60}, N_{120} was developed. Nitrogen fertilization was continued each year after resumption of vegetation. Indigenous grasses were cut 3 times, *Panicum virgatum* 2 times. Other plants were cut once in October. Forest plants (*Salix viminalis, Populus tremula x P. tremuloides, Populus nigra)* were cut after 3 growing seasons late in the autumn (in November) in 2010.

Total C and N content of samples was determined simultaneously by dry combustion (Dumas method) using Vario *EL* III *CNS*-autoanalyser (Elementar, Germany). The water soluble carbohydrate (WSC) content was determined using anthrone method. The samples were also subjected to the fibre component analyses: acid detergent fibre (ADF) and neutral detergent fibre (NDF) and acid detergent lignin (ADL) using cell wall detergent fractionation method according to Van Soest. ADF extraction was done on an ANKOM220 Fibre Analyzer (ANKOM Technology 05/03, Macedon, NY, USA) using F57 filter bags (25-µm porosity).

The air temperature during the growing season of the experimental years (2010-2011) exceeded the long-term averages. In 2010, abundant rainfall was also characteristic of the entire growing season. As a result, conditions were conducive to plant growth. In 2011, the spring and early summer were droughty. Due to the shortage of moisture the plants wilted a little. In both experimental years the winters were cold and snowy.

Results and discussion

The dry matter (DM) yield of plant biomass is an important factor for bioenergy production. Herbaceous plants' dry matter yield was highly dependent on the amount of precipitation. Due to the wet spring and summer of 2010, herbage dry matter yield was nearly twice as high as that in 2011. Droughty spring significantly reduced the yield also of those grasses that are cut only once (*Sida, Artemisia dubia*). The dry matter yield of herbaceous plants that do not fix nitrogen depended on fertilization. Not all the grasses responded identically to nitrogen fertilization. Unfertilized *Sida and Artemisia dubia* produced a dry matter yield of 10.5 – 11.2 t ha^{-1}. However, the highest yield 13.29 t ha^{-1} was produced by unfertilized legume *Galega*. The data averaged over two years showed that

Table 1

The potential of biomass dry matter yield and biometrical data of herbaceous plants, average 2010-2011

Plant	Fertilization	Dry matter yield t ha^{-1}	Dry matter %	No. of shoots/ plants	Length of shoots, cm
Sida hermaphrodita	N60	9.58	51.0	18	271
Artemisia dubia	N60	11.10	49.9		174
Galega orientalis	N0	10.98	18.2		134
Phalaris arundinacea	N120	9.89	31.0		135
Silphium perfoliatum	N60	7.29	38.5	33	208
Helianthus tuberosus	N60	8.56	40.7	81	153
Miscanthus giganteus	N120	7.14	52.1	18	235
Dactylis glomerata	N120	6.14	21.2		110
Panicum virgatum	N120	4.62	26.2		105
Polygonum japonica hybr.	N0	8.74	36.2	10	221
Polygonum sachalinensis	N0	5.13	35.8	7	273
Artemisia vulgaris	N60	3.40	59.5		114
Medicago sativa	N60	6.16	25.3		85
Onobrychis viciifolia	N60	5.21	33.9		75
LSD_{005}		**1.814**			

the highest dry matter yields 11.10-10.98 t ha^{-1} were produced by *Artemisia dubia* and *Galega orentalis,* respectively (Table 1). *Artemisia dubia* was cut only once at the end of vegetation. The fresh mass cut at that time contained 49.9 % of dry matter. Similar amounts of dry matter are accumulated also by short vegetation forest plants that can be used for combustion like *Artemisia dubia.* In our previous research, *Artemisia dubia,* fertilized with N_{60} produced a dry matter yield of 15.6 t ha^{-1} already in the second year of growth. Compared with *Galega orentalis*, *Artemisia dubia* developed much more rapidly and produced a high stand density, which prevented weeds from being established. *Galega* is superior to *Artemisia* in two aspects: it does not need nitrogen fertilization and is easier to establish. *Artemisia dubia* does not mature seed and can be propagated only vegetatively by planting fine-cut rhizomes.

Another two plants promising for bioenergetics are *Sida hermaphrodita* and *Phalaris arundinacea.* Their dry matter yield when fertilized with $N_{60\ -120}$ amounted to 9.58-.9.89 t ha^{-1}. *Sidos* plants cut once were the tallest (271 cm) of all plants. They would suit for direct combustion, since their biomass accumulates 51.0 % of dry matter. In terms of dry matter yield, the other tested plants *Helianhtus*, *Miscanthus* (8.56-7.14 t ha^{-1}), significantly lagged behind the above-discussed plants. *Miscanthus,* which is a subject of great interest in West Europe, in our research, in the 3rd -4th year of use when fertilized with N_{120} produced around 7.0 t ha^{-1} of dry matter. The highest yield (11.53 t ha^{-1}) was obtained in the second year of use (Kryževičienė et al. 2011). Due to the cold winters of 2010 and 2011, *Miscanthus* markedly thinned out. In the spring of 2010, the plants that survived accounted for 54 % of the initial number planted. *Miscanthus* does not mature seed. It is commonly propagated by vegetative method and by planting fine-cut rhizomes. Our test material was obtained from Austria. In Lithuania, *Miscanthus* research should be continued. Other tested plants from *Polygonum* genus are invasive and their propagation in Lithuania is not recommended. Unfertilized they produce a biomass yield of 5.14-8.74 t ha^{-1}. Traditional legumes *Medicago sativa* and *Onobrychis viciifolia* yielded well and surpassed some of the imported plants at least in the first year of use.

When cut 3 times, traditional legumes (*Galega, Onobrychis, Medicago*) accumulated the largest content of nitrogen in dry biomass (Table 2). Traditional grasses contained 2-3 times less nitrogen than legumes. Grasses that accumulate more nitrogen and are cut more frequently are better suited for biogas production than for direct combustion. The C:N ratio also indicates the suitability of grasses for biogas production. For the anaerobic biomethane process to be optimal, carbon to nitrogen ratio (C:N) in biomass is one of the main quality indicators. Literature sources indicate various ranges of C:N values. It is maintained that its optimal value commonly ranges between 20 to 30 (Cotana and Giraldi, 2007); however, some authors showed this value to range from 15 to 30 (Osman et al., 2006). In our study, in the biomass of traditional herbs the range of carbon to nitrogen ratio varied from 15.3 *(Galega)* to 51.5 (*Phalaris).* Thus, according to this indicator, *Phalaris* is better suited for combustion than for biogas production. *Sida and*

Table 2

Chemical composition of the above ground biomass of herbs, 2010

Fertilization	Chemical composition %								
	N	C	S	C:N	Fibre NDF	Fibre ADF	Ash	Lignin	WSC*
Imported plants									
Sida hermaphrodita									
N_0	0.247	47.2	0.046	194.8	82.8	73.5	3.17	12.7	1.54
N_{60}	0.412	47.1	0.046	129.7	79.6	69.3	4.23	11.8	2.18
N_{120}	0.352	47.6	0.045	136.3	81.1	71.4	3.86	13.3	1.44
Silphium perfoliatum									
N_0	0.630	43.2	0.041	75.0	65.1	56.6	13.10	13.8	2.63
N_{60}	0.411	45.1	0.040	124.4	70.7	63.9	9.18	13.0	1.93
N_{120}	0.448	45.7	0.037	102.1	73.7	67.7	7.00	12.1	1.88
Polygonum sachalinensis									
N_0	0.266	47.0	0.037	177.1	91.9	55.5	6.61	19.1	10.50
Polygonum japonica hybrid									
N_0	0.527	47.4	0.034	89.9	69.6	68.3	4.84	20.6	2.60
Miscanthus giganteus									
N_0	0.798	46.8	0.044	62.2	74.3	50.7	4.90	8.4	7.98
N_{60}	0.734	46.2	0.038	63.2	70.0	49.5	3.61	8.2	5.00
N_{120}	0.515	48.2	0.040	97.9	78.5	57.3	2.80	11.7	5.87
Non-traditional plants									
Artemisia vulgaris									
N_{60}	0.455	48.4	0.048	107.6	74.2	66.0	3.95	16.8	3.24
Artemisia dubia									
N_0	0.372	49.3	0.048	135.0	70.1	62.7	4.22	14.6	3.72
N_{60}	0.355	48.9	0.043	138.7	63.4	58.1	4.17	14.0	6.25
N_{120}	0.420	48.8	0.042	117.8	70.1	64.2	4.26	16.4	2.96
Helianthus tuberosus									
N_0	0.715	46.0	0.057	65.1	58.5	48.5	6.15	10.6	13.35
N_{60}	0.505	46.4	0.050	92.6	57.5	50.8	4.97	10.1	19.10
N_{120}	0.525	46.0	0.047	87.8	56.2	47.7	4.61	8.9	19.70
Local plants									
Dactylis glomerata									
N_0	1.720	43.6	0.168	25.4	55.5	44.5	12.95	14.3	5.95
N_{60}	1.725	44.5	0.202	25.9	58.4	45.6	11.15	16.1	5.12
N_{120}	1.725	45.5	0.124	26.4	57.5	38.3	9.35	9.9	6.99
Phalaris arundinacea									
N_0	0.974	44.4	0.249	45.6	58.4	39.9	9.76	7.8	9.54
N_{60}	0.964	45.3	0.230	47.2	61.7	40.0	8.81	7.2	9.81
N_{120}	0.891	45.9	0.273	51.5	64.1	42.8	7.81	8.5	10.27
Galega orientalis									
N_0	3.010	46.1	0.084	15.3	59.2	49.2	9.32	15.4	3.67
Medicago sativa									
N_0	2.365	47.0	0.088	20.20	57.5	49.1	7.67	16.2	5.18
Onobrychis viciifolia									
N_0	2.59	47.1	0.170	18.2	57.9	48.3	8.07	19.2	4.62

*water soluble carbohydrates (WSC)

Table 3

Biomass yield of forest plants, kg ha^{-1} and biometrical data, 2010

Plant	Fertilization	Fresh mass. kg ha^{-1}	Dry matter yield kg ha^{-1}	DM %	No. of shoots / plants	Viable shoots/ plants	Length of shoots cm	Diameter. shoot cm
Salix viminalis	N0	65482	36474		8.2	3.9	570	2.54
	N60	58667	32678	55.7	7.9	5.5	583	2.74
	N120	68445	38124		8.4	4.4	595	2.95
$LSD_{0.05}$		**9741.3**	**5425.8**		0.74	0.83	20.9	0.14
Populus nigra	N0	51333	27053		11.5	11.5	473	2.71
	N60	62667	33025	52.7	12.7	12.7	468	3.50
	N120	45667	24066		10.2	10.2	458	2.83
$LSD_{0.05}$		**16265.6**	**8571.9**		2.10	2.10	21.0	0.26
Populus tremula x P.tremuloides	N0	33000	18744		1.9	1.9	426	3.62
	N60	39000	22152	56.8	3.0	3.0	421	3.16
	N120	27333	15525		2.2	2.2	391	3.00
$LSD_{0.05}$		**8202.7**	**4659.1**		**1.31**	**1.31**	**30.0**	**0.22**

Table 4

Chemical composition of forest plants, 2010

Fertilization	Chemical composition %								
	N	C	S	C:N	Fibre		Ash	Lignin	WSC*
					NDF	ADF			
Salix viminalis									
N_0	0.485	49.5	0.043	113.9	79.4	16.4	4.93	16.8	4.95
N_{60}	0.559	49.7	0.042	89.4	83.4	18.8	4.95	18.0	4.51
N_{120}	0.480	49.3	0.040	104.8	82.6	17.5	4.77	17.5	4.12
Populus tremula x P. tremuloides									
N_0	0.749	50.0	0.046	66.8	67.4	57.3	2.62	14.3	6.95
N_{60}	0.637	49.1	0.043	77.2	68.3	58.9	2.24	16.6	7.03
N_{120}	0.771	49.4	0.045	64.2	69.6	58.1	2.77	15.5	6.80
Populus nigra									
N_0	0.658	49.1	0.045	76.9	75.1	69.8	2.58	19.4	5.26
N_{60}	0.674	49.4	0.046	75.2	71.3	66.3	3.01	19.1	6.23
N_{120}	0.596	49.3	0.043	84.9	76.4	69.7	2.51	19.2	5.09

*water soluble carbohydrates (WSC)

Artemisia accumulated the lowest levels of nitrogen in dry matter, which confirms their suitability for direct combustion. Higher sulphur contents accumulated in traditional grasses that were cut more frequently. The lowest sulphur contents were accumulated in *Artemisia, Miscanthus, Silphium* and *Sida* plants. Elevated sulphur contents in the biomass are undesirable, especially if it is used for combustion, because sulphur compounds which form in the smoke pollute the environment. NDF is a very important component showing biomass suitability for bioenergetics. The highest fibre content was accumulated in the biomass of *Sida* and *Miscanthus*. It is natural that the more frequently the grass is cut, the less fibre it contains. Lignin, a constituent of fibre, is undesirable in the biomass intended for biogas production. Its highest content was found in the plants *Polygonum* genus and in the biomass of *Onobrychis.* Higher contents of soluble carbohydrates accumulated in *Helianthus tuberosus* (13.3-19.7 %) and traditional grasses (3.6-10.7 %). Soluble carbohydrates increase biogas yield. Ash is unwanted in the biomass intended for combustion.

The lowest ash contents (2.80 - 4.90 %) were accumulated in the biomass of *Sida* and *Miscanthus*.

Nitrogen fertilization had little effect on the chemical composition of biomass. There were found larger differences in chemical composition between species.

After three years of cultivation, short-rotation forest plants were cut after leaf-fall in November 2010. Over the three years, the highest dry matter content (32.7-38.1 t ha^{-1}) in the biomass was accumulated by *Salix viminalis*, while the lowest content (15.5.-22.1 t ha^{-1}) was accumulated by *Populus tremula x P.tremuloides* (Table 3).

Compared with the best-yielding herbaceous plants (*Artemisia dubia, Galega, Sida),* biomass yield was similar. What plants to grow will depend on specific needs and circumstances. Nitrogen fertilization did not give any significant increase in the biomass yield of short-rotation plants. This can be explained by the fact that forest plants were grown in nutrient-rich arable land.

The cut woody plants contained 52.7-56.8 % of dry matter. The tallest plants (595-570 cm) were *Salix viminalis*. The greatest number of stems per bunch (10.2-12.7) was found for *Populus nigra.* Nitrogen fertilization significantly increased stem diameter for *Salix viminalis.*

The lowest nitrogen content (0.48-0.56 %) was accumulated in *Salix viminalis* dry biomass (Table 4). The C:N ratio in its biomass was the highest. The *Salix viminalis* biomass also contained the highest concentration of fibre (NDF) 79.4-83.4 %. However, it contained a fairly high level of ash 4.77-4.95 %.

According to ash content, *Salix viminalis* biomass compared to that of *Artemisia dubia*. The lowest ash content was found in *Populus tremula x P. tremuloides* biomass. This can be explained by the fact that *Populus tremula x P. tremuloides* had the fewest but thick stems. Thus there was relatively lower content of bark in the biomass compared with other tree species.

Higher soluble carbohydrate contents were also accumulated here. Carbon and sulphur contents were similar in the biomass of all tree species. Nitrogen fertilization did not have any significant effect on the chemical composition of tree biomass.

Conclusions

Research into the biomass accumulation in various plants showed that in the imported plants' group, the highest dry matter yield (9.58 t ha^{-1}) was produced by *Sida hermaphrodita* when cut once. Other plants of this group were less productive: dry biomass yield of *Silphium perfoliatum* was 7.29 t ha^{-1}, of *Polygonum japonica, Polygonum sachalinensis* 8.74-5.13 t ha^{-1}, respectively. Of the non-traditional plants, the highest biomass content was accumulated by *Artemisia dubia* (11.10 t ha^{-1}) and *Helianthus tuberosus* (8.56 t ha^{-1}), *Artemisia dubia* biomass was 3.3 times as high as that of *Artemisia vulgaris*. In the group of local plants, unfertilized *Galega orientalis* produced 10.98 t ha^{-1} of dry biomass over 3 cuts. *Phalaris arundinacea,* fertilized with N_{120} kg ha^{-1}, produced 9.89 t ha^{-1}.

Forest plants were cut after 3 growing seasons. The largest amount of dry biomass was produced by *Salix viminalis* 32.7-38.1 t ha^{-1} and *Populus nigra* 24.0-33.0 t ha^{-1}. When forest plants were grown in arable land, nitrogen fertilization had little effect on biomass yield, a biomass reduction trend was observed at fertilizing with N_{120} kg ha^{-1},. *Salix viminalis* also had low nitrogen and sulphur contents. *Salix viminalis* was best suited for combustion.

The amounts of biomass produced by the best-yielding herbaceous plants were similar to those produced by short-rotation forest plants. The choice of plants intended for bioenergetics will depend on specific local conditions, needs and circumstances.

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