Phytomass as a renewable energy source in conditions of the Czech Republic

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Abstract

A new research carried out in 2018 – 2020 addressed the use of grasses as catch crops in order to determine the production of dry matter and energy in selected grass species and their mixtures. Mixtures of Lolium perenne 'Kentaur', Festuca rubra 'Zulu' and Festuca arundinacea 'Kora' were included in the research. Grasses were established during the business year in three terms as summer, stubble and winter catch crops. In 2019, the dry matter yield of selected grass mixtures ranged between 5.5 t.ha^{-1} and 12.7 t.ha^{-1}. The stated yields correspond to a tonne of coal equivalent of 3.33 t.ha^{-1} to 7.6 t.ha^{-1}. Dry matter yield in 2020 for selected grass mixtures ranges between 5 t.ha^{-1} and 12.3 t.ha^{-1}. The stated yields correspond to a tonne of coal equivalent of 3.03 t.ha^{-1} to 7.36 t.ha^{-1}. At the same time, dry matter production was monitored in 2018 – 2020 on an uncultivated land, former meadows and an arable land at one site. Dry matter production ranged between 1.08 and 1.53 t.ha^{-1}. This also corresponds to the energy production of 0.62-0.92 t.ha^{-1} equivalent tonne of coal equivalent. The total production of dry matter and energy is 6–8 times lower compared to the monitored grass mixtures usable as catch crops. The occurrence of weeds dangerous in sowing procedures of agricultural production such as Elymus repens, Cirsium sp., Rumex sp. has been reported on an uncultivated land. From an agricultural and landscape perspective such negative phenomena in the form of spontaneous fallow land must be eliminated. Intercrops increase the stability of the landscape agroecosystem, especially in relation to soil, and based on this research grasses grown as intercrops can be recommended and used in agricultural sowing practices. The resulting biomass of catch crops can be used for bioenergy purposes.

***Keywords:** Grass, catch crops, dry matter, tonne of coal equivalent, spontaneous fallow*

Introduction

Grasses are a large and diverse family of *Poaceae*, which is represented in the Czech Republic by 64 genera (including important cereals) and more than 200 species[1]. The occurrence of grasses is linked to grassland ecosystems, the most important of which are communities of different types of natural and semi-natural meadows (Figure 1). In the plant system, grasses are monocotyledonous plants that are characterized by the presence of only a single uterine petal and other features such as the type of root system, the structure of the flowers, and the parallel veins of the leaves. They include annual, bi-annual and perennial, non-pollinated and self-pollinated, winter and spring species. Morphologically, they form a relatively unified group[2].

Cagaš[3] states in the Methodology for Agricultural Practice[3]: Grasses as well as their mixtures with various types of clover meet the basic requirements for permanent soil cover, reduce the risk of erosion and the growth of secondary weeds. They also improve physical and chemical condition of the soil, promote the biological life in the soil and, last but not least, offer the immediate readiness to transfer these areas to normal agricultural production. To a greater or lesser extent, grasses and clover can contribute to short-term fallow (1 – 3 years), long-term grassing and produce biomass as an important source of renewable energy. The potential of grass biomass is mainly represented by permanent grasslands (meadows and pastures), lawns, technical areas and purposefully grown grasses for seed harvesting with the use of threshed straw for energy purposes[4, 5].

Grasses can be used to generate heat or electricity in special boilers[6]. Heat or electricity is generated by biogas production. In addition, grass biomass is used to produce briquettes or pellets as a fuel for heating[7, 8].

Further research has been also carried out on the use of grass to produce second generation bioethanol and biodiesel from lignocellulose. Bioethanol is produced by a biotechnological method (anaerobic fermentation by yeast or bacteria), while biodiesel is produced by a thermochemical method using synthesis gas, which can then be chemically converted, for example, by the Fischer-Tropsch method[6]. Grass biomass can also be processed by torrefaction, i.e. thermochemical decomposition without air access. Grass biomass acquires higher calorific value, lower humidity and hydrophobic character[9].

The possibilities of using the potential of grass biomass are very topical. Research into the use of grasses for energy purposes was carried out in three stages. In the first stage of the research, the most suitable grasses for energy purposes were selected and monitored from the group of grass species in terms of green matter yield, dry matter and dry mass, gross calorific value and net calorific value. These included the selection of the best grasses for energy purposes suitable for the conditions in the Czech Republic, such as *Agrostis gigantea* (redtop) 'Rožnovský', *Festuca arundinacea* (tall fescue) 'Kora' and *Arrhenatherum elatius* (tall oatgrass) 'Rožnovský'. At the same time, several varieties of *Phalaris arundinacea* (reed Canary grass) were also verified. This grass species is also very suitable for use in phyto energetics. *Phalaris arundinacea* 'Chrastava' variety was cultivated for the conditions in the Czech Republic by OSEVA Development and Research Ltd. in Zubří. At the same time, an uncultivated land, so-called spontaneous fallow has been also assessed, including botanical evaluation thereof. The dry matter yield of spontaneous fallow grasslands was low (up to 2 $t.ha^{-1}$).

In the second stage of the research, the yield parameters of grasses were verified. These include the yield of green matter, dry matter, dry mass and its content. These parameters were determined for grass species and meadow mixtures that were included in the research in the period of one to two months before the harvest maturity of grasses for seed and in the period within two months after the harvest maturity of grasses for seed. The aim was to determine the most suitable date for the highest dry matter yield harvest. At the same time, combustion tests of grass biomass in small (heat output up to 50 kW) and large boilers (500 kW–2 MW of heat) took place. Thus, a suitable energy producing device (boiler) was determined, in which grass biomass can be burned[10].

The third stage of energy grass research focused on monitoring biogas production. The research of grass biomass combustion and biogas production was carried out by OSEVA Development and Research Ltd. in Zubří in cooperation with the University of Mining and Technology in Ostrava and the Research Institute of Agricultural Technology in Prague[10].

During the period 2018 – 2020, the production of selected grass species and their mixtures grown as catch crops was the subject of a new research in order to determine the dry matter yield and energy production. The production of dry matter and energy of grass mixtures grown as catch crops was compared with the production of spontaneous fallow established on an uncultivated land.

Figure 1: Phytomass in Beskydy in the area of the OSEVA Development and Research Zubří

Material and methods

The 2018 – 2020 research project was divided into two parts. In the first part of the research project, grass mixtures were established at three terms during the year as summer, stubble and winter catch crops. The first results showed that the inclusion of catch crops in sowing procedures prolongs the time of soil cover and thus affects a number of factors, especially in terms of soil protection and by increasing its fertility. Intercrops increase the long-term stability of the agroecosystem, especially in relation to the soil in the landscape. In the case of the grass mixtures, dry matter yield and energy production were monitored. In the second part of the research project, spontaneous fallow on an uncultivated land were selected. Dry matter yield and energy production were determined for these fallow lands. The resulting production of grass mixtures was compared with the production of dry matter and energy on the uncultivated land.

Characteristics of grass species included in the research

***Lolium perenne* L.** (perennial ryegrass) – the variety 'Kentaur' is tetraploid ryegrass with medium to late heading time, intended for pasture use, which was registered in the State Variety Book of the Czech Republic in 2002. The variety is resistant to snow mould infestation, less resistant to leaf spots and moderately resistant to rust infestation (ÚKZÚZ, 2020). The variety was bred by crossing and subsequent selection of late types of foreign tetraploid varieties.

***Festuca rubra* L.** (red fescue) 'Zulu' variety starts growth very early in the spring and early production of green matter, significantly earlier than other permitted varieties, is bushy and of perennial character. Due to the favourable spring overgrowth it is also suitable for ordinary, less demanding grass-plots even in drier conditions. The variety was registered in the State Variety Book of the Czech Republic in 1974 under the name 'Valaška' and was bred from ecotypes found in permanent grasslands in Wallachia[11]. *Festuca rubra* is also suitable for phytostabilization of soil[12].

***Festuca arundinacea* Schreb.** (tall fescue) – is suitable for pastures, for the production of hay and silage, but also for storing the soil at rest[13]. *Festuca arundinacea* 'Kora' is an early to medium early variety, suitable for meadow and pasture use. Spring growth is very fast, grows densely after mowing. Resistant to snow fungus. Tolerates summer droughts and wetting well. The variety was registered in the State Variety Book of the Czech Republic in 1989 and was bred by crossing foreign varieties with Northern Moravia ecotype (Bílovec). The variety has a very good durability[11].

Grasses and grass mixtures were sown in 2018 and 2019 during experiments in various ways and at different times in a small field plot establishment with a plot size of 10 m^2 and rows spacing of 21 cm. At the same time, three sowings of grass mixtures were tested in June, September and in October in 2018 and 2019.

The experimental plots of herbage were fertilized with NPK nitrogen fertilizer with a dose of 40 kg $N.ha^{-1}$ before sowing. Further fertilization was carried out in the spring of the following year by a dose of 55 kg $N.ha^{-1}$ of ammonium nitrate with limestone. In 2018 and 2019, *Lolium perenne* 'Kentaur', *Festuca rubra* 'Zulu' and *Festuca arundinacea* 'Kora' were included in the research. Two two-component mixtures were created, the first with *Lolium perenne* 'Kentaur' a *Festuca arundinacea* 'Kora', sowing 10 kg and 20 $kg.ha^{-1}$. The second mixture contained *Lolium perenne* 'Kentaur' and *Festuca rubra* 'Zulu'. It was also established with a sowing rate of 10 kg and 20 $kg.ha^{-1}$. These mixtures were established in June, September and October in 2018 and 2019. In June of 2019 and 2020 harvesting of the grass mixtures of the first crop established in 2018 and 2019 was carried out (Figure 2). The dry matter yield was then determined and the dry matter yield of selected grass mixtures was converted to a ton of coal equivalent, which will be replaced by the stated amount of biomass harvested in the established mixtures. The values of gross calorific value and net calorific value were also determined.

Figure 2: Grass mixtures in 2020

Habitat characteristics

The catch crops experiments were based on OSEVA Development and Research Ltd. habitat. The habitat lies in Zubří at an altitude of 345 m. The long-term average annual temperature is 7.5 °C and the long-term annual rainfall is 864.5 mm. The long-term average temperature for the growing season is 14.3 °C and the long-term total rainfall for the growing season is 546.8 mm. The land on the station is located in climate region 7 — moderately warm. The experiments were based on medium sandy soil in the years tested. Spontaneous fallow were assessed in Hustopeče nad Bečvou, which is at an altitude of 275 m. They are also in climate region 7. Fallow were predominantly on light sandy and medium sandy-brown soil in the Hustopeče nad Bečvou in the village Velká Lhota at an altitude of 540 m. They were assessed in a former hay and hay-harvesting meadow.

Biomass samples from an uncultivated land with an area of four times one metre were harvested. Dry matter yield, gross calorific value and net calorific value were determined according to CSN EN ISO 18125 on IKA C6000. In 2018 – 2020 an evaluation of fallow land in the area of Hustopeče nad Bečvou and in 2018 another evaluation of one fallow land in the area of Velká Lhota were carried out. The fallow land harvest time during the experimental years took place at the turn of October and November.

Results and discussion

I. part of the research project in 2018–2020

The result of this first part of the research are the yields of dry matter and production of energy of the proposed grass mixtures as intercrops. Table 1 lists parameters for the mixture of *Lolium perenne* with *Festuca arundinacea*, and Table 2 for the mixture of *Lolium perenne* with *Festuce rubra.*

Table 1: Dry matter yields and energy production of a mixture of Lolium perenne and Festuca arundinacea in 2019

Evaluation	***Lolium perenne + Festuca arundinacea***				
Seed rate (kg.ha^{-1})	20	10	20	10	20
Sowing dates	June		September		October
Dry matter yield (t.ha^{-1})	12.7	11.5	11.7	10.9	5.7
Gross calorific value of dry matter (GJ.t^{-1})	17.96				
Energy production (GJ.ha^{-1})	224.00	203.00	207.00	195.00	106.00
Standard deviation	0.11	0.16	0.12	0.09	0.10
Range	0.30	0.56	0.33	0.25	0.27
Tons of coal equivalent (t.ha^{-1})	7.60	6.89	7.01	6.59	3.41

Table 2: Dry matter yields and energy production of a mixture of Lolium perenne and Festuca rubra in 2019

Evaluation	***Lolium perenne + Festuca rubra***					
Seed rate (kg.ha^{-1})	20	10	20	10	20	20
Sowing dates	June		September			October
Dry matter yield (t.ha^{-1})	11.8	11.0	11.4	10.5	10.0	5.5
Gross calorific value of dry matter (GJ.t^{-1})	18.45					
Energy production (GJ.ha^{-1})	207.00	193.00	200.00	184.00	179.00	98.00
Standard deviation	0.20	0.20	0.24	0.20	0.21	0.18
Range	0.57	0.64	0.72	0.60	0.64	0.56
Tons of coal equivalent (t.ha^{-1})	7.02	6.54	6.78	6.24	6.05	3.33

Dry matter yield in 2019 of selected grass mixtures ranges between 5.5 t.ha^{-1} and 12.7 t.ha^{-1}. The stated yields also correspond to the equivalent of a tonne of coal equivalent between 3.3 t.ha^{-1} and 7.6 t.ha^{-1} (Table 1 and 2). The lowest yields of dry matter and energy production are noted in the variant of the experiment established in October 2019.

Dry matter yields of the same mixtures for 2020 are shown in Table 3 and 4.

Table 3: Dry matter yields and energy production of a mixture of Lolium perenne and Festuca arundinacea in 2020

Evaluation	***Lolium perenne + Festuca arundinacea***				
Seed rate (kg.ha^{-1})	20	10	20	10	20
Sowing dates	June		September		October
Dry matter yield (t.ha^{-1})	12.3	11.3	10.6	10.3	5.3
Gross calorific value of dry matter (GJ.t^{-1})	17.96				
Energy production (GJ.ha^{-1})	217.00	200.00	187.00	182.00	94.00
Standard deviation	0.22	0.21	0.14	0.17	0.10
Range	0.57	0.60	0.40	0.48	0.28
Tons of coal equivalent (t.ha^{-1})	7.36	6.76	6.35	6.17	3.17

Table 4: Dry matter yields and energy production of a mixture of Lolium perenne and Festuca rubra in 2020

Evaluation	***Lolium perenne + Festuca rubra***					
Seed rate (kg.ha^{-1})	20	10	20	10	20	20
Sowing dates	June		September			October
Dry matter yield (t.ha^{-1})	11.4	10.7	10.2	9.7	8.9	5.0
Gross calorific value of dry matter (GJ.t^{-1})	18.45					
Energy production (GJ.ha^{-1})	200.00	188.00	179.00	170.00	159.00	89.00
Standard deviation	0.12	0.17	0.07	0.16	0.14	0.16
Range	0.27	0.47	0.19	0.45	0.34	0.44
Tons of coal equivalent (t.ha^{-1})	6.78	6.36	6.06	5.77	5.39	3.03

A tonne of coal equivalent is a fuel derived from black coal. Its net calorific value is 7 000 kcal.kg^{-1} (i.e. 29.3076 GJ.t^{-1}). It is used as large volumes of fuel. The values of gross calorific value and net calorific value, listed in Table 5, were determined in the Research Institute of Agricultural Engineering, p.r.i. in Prague.

Table 5: Average values of gross calorific value and net calorific value for grasses and grass mixtures included in the research in 2018–2020 in 100 percent dry matter

Grass species and mixtures	Gross calorific value kJ.kg^{-1}			Net calorific value kJ.kg^{-1}
	Average	Standard deviation	Range	
Lolium perenne	18 155.0	5.8	62.0	17 862
Lolium perenne + *Festuca arundinacea* mixture	17 959.0	4.3	57.0	17 666
Festuca rubra	18 450.0	4.4	56.0	17 220
Lolium perenne + *Festuca rubra* mixture	18 303.0	7.2	85.0	17 541

Dry matter yield in 2020 of selected grass mixtures ranges between 5.0 t.ha^{-1} and 12.3 t.ha^{-1}. The stated yields also correspond to the equivalent of a tonne of coal equivalent between 3.03 t.ha^{-1} and 7.36 t.ha^{-1} (Table 3 and 4). The lowest yields of dry matter and the energy output is noted in variants of the experiment established in October 2020. Frydrych[14] discloses energy production of selected grass species in the first stage of research as 0.50 – 6.09 t.ha^{-1} of the coal equivalent per hectare. The highest yield of dry matter (9.72 t.ha^{-1}) and energy production of 6.09 t.ha^{-1} was achieved by *Agrostis gigantea* 'Rožnovský'.

Frydrych[15] states that in the first stage of the research, the proposed grasses were assessed in terms of yield of green matter, dry matter and dry mass. They were analyzed for gross calorific value and net calorific value. Based on the results, three species of grasses most suitable for energy use were determined as follows (*Agrostis gigantea* 'Rožnovský', *Festuca arundinacea* 'Kora' and *Arrhenatherum elatius* 'Rožnovský'). The yield of these three grass species ranged on average between 8 and 10 t.ha^{-1} of dry matter in the conditions of Zubří in the fertilized variant. The grasses were tested in the variant without fertilization and with the variant fertilized with 50 kg N.ha^{-1} per year.

Grasses and meadow mixtures included in the second stage of the research were harvested as whole plants at the monthly intervals between May and September. The highest dry matter yields in all three harvest years were achieved in the third cropping year by *Phalaris arundinacea* 'Palaton' 11.89 t.ha^{-1}, *P. arundinacea* 'Chrastava' 11.76 t.ha^{-1}, *P. arundinacea* 'Chrifton' 11.20 t.ha^{-1}, *Agrostis gigantea* 'Rožnovský' 11.12 t.ha^{-1} and *Festuca arundinacea* 'Kora' 10.69 t.ha^{-1}. All these yields were achieved in the fertilized variant of 50 kg N.ha^{-1} in the month of August in three harvest years. The highest dry matter yield was achieved by grasses during the harvest of whole plants in the period from July to August, i.e. during the period of harvest maturity for seed and one month after this harvest maturity for seed.

Strašil[16] mentions one of the alternative crops, *Festuca arundinacea*, the widespread cultivation of which is being considered for energy or industrial use. From an energy point of view, *Festuca* can be used for direct combustion or cogeneration (electricity and heat production). In our conditions, the yields of phytomass dry matter range between 5 and 13 t.ha^{-1}.

It is the speed of development after sowing that is important when utilising grasses as intermediate crops. The speed of development as well as the degree of duration is governed not only by the biological properties of individual grass species, but also by habitat conditions and by the applied agricultural engineering. With the right agronomical practices and rational use, it is possible to significantly increase the durability of grasses through growing technologies. Rapid growth exhibiting *Lolium perenne* and moderately fast growing *Festuca rubra* and *Festuca arundinacea*[17] were selected for the research.

Grasses and their mixtures are useful as catch crops. Grasses can be established as summer, stubble and winter catch crops. The highest dry matter yield and energy production was achieved by a mixture of *Lolium perenne* and *Festuca arundinacea* in sowing 20 kg.ha^{-1} in the first and second sowing dates in June and September in both experimental years. (Table 1 and 3). *Festuca arundinacea* 'Kora' is characterized by considerable adaptability to different habitat conditions and is one of the grasses with the widest habitat amplitude. *Festuca arundinacea* tolerates well both short-term drought and wetlands.

Lolium perenne showed a rapid initial development compared to *Festuca arundinacea* and *Festuca rubra*. *Lolium* and their mixtures can be recommended as intermediate crops in spring, late summer and early autumn with good biomass yield potential. *Lolium multiflorum* var. *italicum* (Italian ryegrass) and *Lolium multiflorum* var. *westerwoldicum* (annual ryegrass) can also be used as intermediate crops. Cagaš[2] characterizes *Lolium multiflorum* var. *italicum* as the most important grass species for intensive forage production on arable land, which is also grown as a fast-growing intercrop.

Based on the research results, it is possible to unambiguously recommend sowing rates for mixtures of *Lolium perenne* with *Festuca arundinacea* and *Festuca rubra* of 20 kg.ha^{-1} (representing a 50% share in cases of individual types of two-component mixtures) and *Lolium perenne* 20 kg.ha^{-1} (cit.[17]).

II. part of a research project in 2018 – 2020

The result of this II. part of the research include dry matter yields and energy production of spontaneous fallows on an uncultivated land.

Research of spontaneous fallows on uncultivated land

The production of proposed grasses and their mixtures for use as intermediate crops, when this material is suitable for energy purposes, was jointly monitored with the biomass production on an uncultivated land in the area of Beskydy Mountains in Hustopeče nad Bečvou locality in 2018 – 2020 and 2018 in Velká Lhota (Table 6 – 8). Low production of dry matter at individual sites was proven by the evaluation of these meadows, the harvest materials and the arable land used already in the past for hay and silage. Negative outcomes of these in the past assessed spontaneous fallow lands in the area of Beskydy (Zubří and the Prostřední Bečva) were noted from the agricultural, soil and landscape point of view in the area where they occur. In terms of agricultural concerns the largest weed population found at all fallow lands comprised of the most dangerous species, namely *Elymus repens* (quackgrass), *Cirsium arvense* (Canada thistle), *Rumex crispus* (curly dock) *R. obtusifolius* (bitter dock) and *R. conglomeratus* (clustered dock). The highest costs in agricultural production in the area of plant protection are incurred by protecting plants against these weeds. Moreover, soil fertility is reduced by the depletion of nutrients by these weeds. The fallow lands that are the source of these weeds are almost always adjacent to the agricultural sites. The probability of weeds spreading from these "foci" even over a distance of several kilometres is high. In addition to this negative phenomenon, there is also a high likelihood of a certain accumulation of diseases and pests on these spontaneous fallow lands. It is a well-known fact that weeds are carriers of numerous diseases and pests harmful to cultivated plants, besides the fact that they also allow their development and further spread of such diseases and plant pests. Dry matter yield on spontaneous fallow lands is very low[14].

Table 6: Dry matter yield and energy value of spontaneous fallow lands in the area of Hustopeče nad Bečvou and Great Lhota in 2018

Fallow land name	Culture	Dry matter yield t.ha^{-1}	Energy production			
			Average GJ.ha^{-1}	Standard deviation	Range	Tons of coal equivalent per hectare
Štěrk	Arable land	1.36	23.77	0.49	0.14	0.74
Velká Lhota*	Meadow	1.14	20.94	0.06	0.16	0.68
U Obory	Meadow	1.28	23.81	0.07	0.20	0.75

**in 2018, a sample of the fallow land was taken at the Velká Lhota site*

Table 7: Dry matter yield and energy value of spontaneous fallow lands in Hustopeče nad Bečvou in 2019

Fallow land name	Culture	Dry matter yield t.ha^{-1}	Energy production			
			Average GJ.ha^{-1}	Standard deviation	Range	Tons of coal equivalent per hectare
Štěrk	Arable land	1.40	26.32	0.06	0.16	0.83
Bečviska	Meadow	1.12	21.00	0.06	0.18	0.66
U Obory	Meadow	1.31	24.29	0.06	0.16	0.77
Poruba	Meadow	1.25	23.28	0.04	0.12	0.73

Table 8: Dry matter yield and energy value of spontaneous fallow lands in Hustopeče nad Bečvou in 2020

Fallow land name	Culture	Dry matter yield t.ha^{-1}	Energy production			
			Average GJ.ha^{-1}	Standard deviation	Range	Tons of coal equivalent per hectare
Štěrk	Arable land	1.53	27.22	0.09	0.24	0.92
Bečviska	Meadow	1.29	21.45	0.06	0.16	0.72
U Obory	Meadow	1.17	19.76	0.12	0.32	0.67
Poruba	Meadow	1.08	18.38	0.06	0.16	0.62

The values of gross calorific value and net calorific value, given in Table 9, were also determined in the Research Institute of Agricultural Engineering, p.r.i. in Prague.

Table 9: The average of gross calorific value and net calorific values in dry matter, spontaneous fallows on arable land in 2018–2020

Fallow land name	Culture	Gross calorific value, kJ.kg^{-1}			Net calorific value kJ.kg^{-1}
		Average	Standard deviation	Range	
Velká Lhota	Meadow	18 370.0	4.3	52.0	17 616
Štěrk	Arable land	18 463.0	4.3	53.0	17 217
Bečviska	Meadow	18 345.0	4.3	51.0	17 060
U Obory	Meadow	18 440.0	5.8	83.0	17 140
Poruba	Meadow	18 475.0	5.8	87.0	17 162

In the first stage of research and possible replacement of an uncultivated land with cultural grass in the past, large tracts of land in the order of 1 – 5 ha were monitored in the Zubří and the Prostřední Bečva areas. In 2018 – 2020 in the area of Hustopeče nad Bečvou and in 2018 in the area of Velká Lhota, these consisted of enclaves up to the size of 0.2 – 0.5 ha. Spontaneous fallow land with meadows for hay harvesting predominated. In terms of the botanical composition species *Elymus repens*, *Calamagrostis arundinacea* (bunch grass in the family *Poaceae*), *Phalaris arundinacea*, *Deschampsia cespitosta* (tufted hairgrass), *Cirsium* sp., *Rumex* sp., *Urtica dioica* (stinging nettle) and *Convolvulus* sp. (bindweed) prevailed on these fallow lands. Species *Elymus repens*, *Dactylis glomerata* (orchard grass), *Holcus lanatus* (velvet grass), *Calamagrostis arundinacea*, *Cirsium* sp., *Urtica dioica, Rumex* sp. and *Aegopodium podagraria* (bishop's goutweed) occured in the area of Velká Lhota. The yield from dry matter and energy production on spontaneous fallow lands during the monitored years of 2018 – 2020 was very low; it ranged between 1.08 and 1.53 t.ha^{-1} (Table 6, 7, 8). This corresponds with the energy production between 0.62 and 0.92 t.ha^{-1} of coal equivalent from a hectare. Total dry matter production and energy is 6 – 8 times lower than the monitored compositions usable as grass crops. At the same time, we can consider the weeds on these fallow lands to be undesirable from an agricultural point of view, especially by the occurrence of couch grass, plum thistle and sorrels. The solution is to use this uncultivated land for harvesting biomass, grass the former meadows and the arable land, harvest hay for livestock or use it for energy generation purposes. In 2020 harvest began at the former fallow at U Obory, which is used for hay and haylage by a horse breeding farmer. It is not recommended to leave the land uncultivated as spontaneous fallow land due to negative phenomena from an agricultural and landscape point of view. Frydrych[14] indicates the dry matter yield at 0.78 $t.ha^{-1}$ to 1.34 $t.ha^{-1}$ for fallow land on former pastures and arable land in the Zubří and the Prostřední Bečva areas) in the first stage of energy grass research. This corresponds to the equivalent of a tonne of coal equivalent of 0.48 – 0.78 $t.ha^{-1}$ from this uncultivated land.

Conclusion

Phytomass is an important part of the renewable energy sources in the Czech Republic. During 2018–2020, a new research was undertaken, including the use of grasses as intermediate crops established in three terms of the business year as summer, stubble and winter. The production of dry matter in selected grass mixtures and the production of energy, which represents the equivalent of a tonne of coal equivalent , were established (dry matter production from 1 ha will replace the stated amount of black coal in tonnes). The research includes the mixture of ryegrass with tall fescue and ryegrass with creeping fescue. In these variants, the grasses can be used as catch crops. In 2019, the dry matter yield of selected grass mixtures reached was between 5.5 $t.ha^{-1}$ and 12 $t.ha^{-1}$. The stated yields also correspond to the equivalent of a tonne of coal equivalent between 3.33 $t.ha^{-1}$ and 7.6 $t.ha^{-1}$. Dry matter yield in 2020 for selected grass mixtures ranges between 5 $t.ha^{-1}$ and 12.3 $t.ha^{-1}$. These yields also correspond to the equivalent of a tonne of coal equivalent between 3.03 $t.ha^{-1}$ and 7.36 $t.ha^{-1}$. The highest dry matter yield and energy production was achieved by a mixture of *Lolium perenne* and *Festuca arundinacea* in sowing of 20 $kg.ha^{-1}$ in the first and second sowing period in June and September in both experimental years. Based on the results, it is therefore possible to clearly recommend sowing rates for mixtures of *Lolium perenne* with *Festuca arundinacea* and *Festuca rubra* of 20 $kg.ha^{-1}$ (they represent a 50% share for individual types of two-component mixtures). The lowest yield of dry matter and energy was reached by the mixture during the autumn sowing in October as a winter intermediate crop in 2018 and 2019.

At the same time, during the years 2018–2020, the production of dry matter on the uncultivated land of former meadows and one locality of former arable land was monitored. It ranged between 1.08 and 1.53 $t.ha^{-1}$. This also corresponds to the energy production between 0.62 and 0.92 $t.ha^{-1}$ of coal equivalent. The total production of dry matter and energy is 6 – 8 times lower compared to the monitored grass mixtures usable as intermediate crops.

During the same time the occurrence of dangerous weeds in agricultural production was recorded on this uncultivated land, such as *Elymus repens*, *Cirsium* sp. and *Rumex* sp. Negative phenomena, which spontaneous fallow land represent, must be eliminated from both an agricultural and a landscape point of view. By grassing and properly managing former spontaneous fallow lands these areas can be used for the production of biomass usable for livestock and energy production. Intercrops increase the stability of the landscape agroecosystem, especially in relation to soil, and grasses grown as intercrops can be recommended and used in agricultural sowing practices on the basis of this research.

Possibilities for establishing grasses as catch crops at three establishment dates have been verified. Grasses and their mixtures are usable as intermediate crops. The mixtures of *Lolium perenne* in particular with *Festuca arundinacea* and *Lolium perenne* with *Festuca rubra* can be recommended for the sowing of an intermediate/catch crops established in late spring and early summer. *Festuca arundinacea* is characterised by considerable adaptability to different habitat conditions and is among the grasses with the widest habitat amplitude. This is particularly true of wet claims. *Festuca arundinacea* tolerates both dried and wetter habitats well. *Lolium* sp. and their mixtures can be recommended as catch crops in spring, late summer and early autumn. *Lolium multiflorum* subsp. *italicum* and *Lolium multiflorum* var. *westerwoldicum* can also be used as intermediate crops. Harvested biomass is usable on the basis of research results for energy purposes.

Acknowledgments

This paper financial support from the Ministry of Agriculture within institutional support for the development of the research organization OSEVA Development and Research Ltd. based in Zubri MZE RO-1821 and this paper was supported by the Ministry of Education, Youth and Sports of the Czech Republic under OP RDE grant number CZ.02.1.01 / 0.0 /0.0 / 16_019 / 0000753 "Research Center for Low-Carbon Energy Technologies". This paper originated within the project of long time development of Research Institute of Agricultural Engineering p.r.i. no. RO0618.

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Travní biomasa jako obnovitelný zdroj energie v podmínkách České republiky

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Souhrn

Nový výzkum v letech 2018 – 2020 řešil využití trav jako meziplodin s cílem zjistit produkci sušiny a energie u vybraných travních druhů a jejich směsí. Do výzkumu byly zařazeny směsi Lolium perenne 'Kentaur', Festuca rubra 'Zulu' a Festuca arundinacea 'Kora'. Trávy byly založeny v průběhu hospodářského roku ve třech termínech jako letní, strniskové a ozimé meziplodiny. V roce 2019 bylo u vybraných travních směsí dosaženo výnosu sušiny od 5,5 t.ha^{-1} do 12,7 t.ha^{-1}. Uvedeným výnosům odpovídá ekvivalent tuna měrného paliva 3,33 t.ha^{-1}do 7,6 t.ha^{-1}. Výnos sušiny v roce 2020 u vybraných travních směsí se pohybuje od 5 t.ha^{-1} do 12,3 t.ha^{-1}. Uvedeným výnosům odpovídá ekvivalent tuna měrného paliva 3,03 t.ha^{-1}do 7,36 t.ha^{-1}.

Současně byla v letech 2018 – 2020 sledována produkce sušiny na ladem ležící půdě na bývalých loukách a na orné půdě u jednoho stanoviště. Produkce sušiny se pohybovala od 1,08 do 1,53 t.ha^{-1}. Tomu odpovídá produkce energie 0,62 – 0,92 t.ha^{-1} ekvivalentu tuny měrného paliva. Celková produkce sušiny a energie je 6 – 8krát nižší oproti sledovaným travním směsím využitelným jako meziplodiny. Byl zaznamenán výskyt plevelů nebezpečných v zemědělské výrobě v osevních postupech, jako jsou Elymus repens, Cirsium sp., Rumex sp. na ladem ležící půdě.

Negativní jevy, které představují spontánní úhory, je třeba eliminovat z hlediska zemědělského i krajinářského. Meziplodiny zvyšují stabilitu krajinného agroekosystému, zejména ve vztahu k půdě, a trávy pěstované jako meziplodiny lze do zemědělských osevních postupů na základě tohoto výzkumu doporučit a využít. Výslednou biomasu meziplodin je možné použít pro energetické účely.

Klíčová slova: *Tráva, meziplodiny, sušina, tuna měrného paliva, spontánní úhory*