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ORIGINAL ARTICLE

Energy crops safe cultivation on drained organic soils

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The development of alternative energy is one way to solve the global problem of our time - the energy crisis. Countries in Europe and around the world already have hundreds of thousands of hectares of energy plantations. Ukraine also has significant areas of energy plantations of wood and herbaceous crops. However, there are many environmental issues with the creation of energy plantations. These are soil and climatic conditions and the ecological safety of their cultivation technology. Studies conducted by us on remote by treatment drained organogenic soils of the Supiy River floodplain (Panfilsky Research Station of NSC "Institute of Agriculture NAAS", Ukraine) showed that the plantation cultivation of Giant miscanthus, Almond-leaved willow, Basket willow, Gray willow, and poplar hybrids in 2016-2020, in terms of annual biomass inputs is about 24.9-25.7 tons per 1 ha of dry weight on average. Regarding the safety of cultivation technologies, we have found that under drained old-fallow soils, mineralization of organic matter and accumulation of mobile nitrogen in the active layer of soil under miscanthus plantations and annual crops (267-324 mg per 100 ha of dry soil) is intense, while tree plantations had the lowest indicators (57-120 mg). The content of mobile phosphorus and potassium was highest in tree crop plantations, respectively, 106-172 and 224-462 mg. Their soil content with miscanthus plantations and annual crops were, respectively, 52-66 and 91-171 mg per 100 soil. A significant influence on the content of elements was the process of high total evaporation by tree crop plantations and entering together with capillary water of the bedrock, rich in various mineral compounds, into the active layer of soil. We have found that the creation of wood (willow and poplar) energy plantations on drained old-fallow organogenic soils provides environmentally safe and efficient use, prevents intensive mineralization of the organic mass of peat, and contributes to a significant reduction of pollution of ground and river water by nutrients.
Keywords: willow, soils, organogenic, crops, tree crops, energy crops, mineralization of peat, drained lands, fertility, cultivation technology, poplar.

World experience proves the effectiveness and prospects of growing biomass as a raw material for heating and electricity production. European Union countries already have hundreds of thousands of hectares of energy plantations, their areas are growing every year, and the share of renewable energy in gross final energy consumption reaches 15%, including biomass - about 9%, while in Ukraine 3,6% and 2,3% respectively. Therefore, the development of the biofuel industry in Ukraine and, above all, the widespread introduction of plantations of fast-growing energy crops appears exceptionally urgent and necessary in the current economic conditions (Methodology, 2019; Roik, 2010).

An essential factor in obtaining high yields of biomass energy crops is soil fertility and, above all, the provision of plants with mineral nitrogen. Its regulation is closely connected with environmental ecology. We have established that drained organogenic soils can accumulate up to 500 and more kilograms of mineral nitrogen a year at the expense of mineralization of peat organic matter (Truskavetsky, 2010; Slyusar et al., 2018), which is enough for plants to accumulate a significant number of vegetative mass of crops most demanding to soil fertility in our zone. Such conclusions are substantiated because, according to our analyses and studies of other scientists, 15-20 kg of mineral (ammonium and nitrate) nitrogen in soil per vegetation is enough to accumulate 1 t of dry biomass of energy crops (Truskavetsky, 2010; Slyusar, 2012). Simultaneously, the accumulation of such a large amount of mobile nitrogen in the soil due to groundwater's close location to its surface can lead to pollution of ground and river water (Slyusar, Solyanik, 2013; Slyusar et al., 2012; Ryzhuk, Slyusar, 2006).

To substantiate the safe and effective use of drained organic soils under the cultivation of various crops, we need to identify the crops and technologies, which would use peatlands' mineralization products and prevent intensive schedule and pollution of the environment. Simultaneously, this direction's research volume is limited (Slyusar, Solyanik, 2013; Slyusar et al., 2012; Ryzhuk, Slyusar, 2006). To solve this problem, we laid experiments, the results of which are presented in this article.

The work aimed to substantiate environmentally safe technologies of cultivation and the selection of energy crops on the effective use of drained organogenic soils, preventing excessive mineralization of peatlands and leaching of nutrients into groundwater.

Methods

Studies were conducted according to generally accepted methods (Ushkarenko et al., 2013) in a stationary field experiment on medium-deep (1.8-2.0 m) dried old plow carbonate peat bog, withdrawn from intensive cultivation, in the floodplain of the Supiy river in the forest-steppe zone (Panfilskaya experimental station NSC "Institute of Agriculture National Academy of Agrarian Sciences", Yahotin district of Kyiv region, Ukraine). Gross nitrogen content in peat soils was 1.9%, phosphorus - 0.45, potassium - 0.17, calcium - 26-30%, ash content was 40-45%, pH of aqueous solution was 7.2-7.4. The soil was well supplied with nitrogen, which accumulates as a result of peat mineralization, had an average supply of phosphorus, which accumulates after mixing vivianite layers with organogenic soil during plowing, and had minimal potassium content. Therefore, only potassium and phosphorus fertilizers were applied in the experiment.

Groundwater level was measured on a decadal basis throughout the year in constructed wells. Soil moisture content in soil samples was determined by the thermostatic weight method in the soil layer 0-30 cm in the first decade of each month during the growing season, nitrate-nitrogen content – by Grandval-Lajoux phenoldisulfonic acid method, mobile phosphorus forms – by B.T. Machigin, mobile potassium forms – by flame photometry of carbon-ammonium extract by B.T. Machigin. The yield was counted by weighing from the counting plot in triplicate. The dry mass of tree crops was collected once every two years after three years from establishing the plantation. Weather conditions of vegetation (April-September) periods 2016-2020 on the experimental field according to the data of Yagotinsky hydrometeorological station, placed at a distance of 2 km, were characterized by a temperature regime close to the norm - 17.5 °C (with fluctuation by year 17.2-18.1 °C) with the norm 17.7 °C and significantly less precipitation. The amount of precipitation in all years of the study averaged 215 mm (with fluctuations by year 165-279 mm), which was almost 34% less than 327 mm. The amount of precipitation at the normative values level was recorded only in the growing season 2016 - 319 mm (Ushkarenko et al., 2013).

Results

Observation of soil moisture and groundwater levels showed that plants were fully provided with moisture regardless of the period and amount of precipitation. The groundwater level during the growing season averaged 64-108 cm from the soil surface and only in August dropped to 130-150 cm, which had little effect on the growth and development of all crops grown during the study years (2016-2020). Such a groundwater table regime was provided by the operation of a drainage-humidifying system constructed in the Supiy river floodplain. This system of lowering groundwater levels beyond optimal parameters using sluicing and supplying water from the central canal ensured additional water inflow into canals and direct subsoil moistening. This is evidenced by observations of moisture content of the active soil layer, which during the growing season did not exceed 80% of total moisture capacity and did not fall below the lower limit of optimal soil moisture - 40%.

Table 1. Nutrient content in the 0-30 cm soil layer depending on crops and fertilizers (Supiy River floodplain, the average for 2016-2019, mg per 1 kg of dry soil)

Crop	NO_3		P_2O_5		K_2O	
	Without fertilizers	K_{120}	Without fertilizers	K_{120}	Without fertilizers	K_{120}
Almond-leaved willow	118	120	172	171	324	328
Basket willow	85	125	160	170	301	327
Gray willow	-	118	-	167	-	462
Toropogritskiy hybrid black poplar	70	130	125	127	297	419
Hybrid Robusta poplar	60	86	126	102	288	406
Poplar I-214	57	87	105	114	224	447
Giant miscanthus	290	324	52	53	91	171
Perennial grasses of constant sowing[2]	49	96	69	90	145	170
Perennial herbs of first year cultivation[2]	140	177	68	79	195	200
Corn for grain[2]	212	267	59	66	128	144

Note 1 - average content values from the four variants of the density of planting miscanthus; 2 - data of the stationary experiment with crop rotations, which borders with planting energy crops.

Agro-ecological features of growing all crops, including energy crops, are closely related to the overall soil fertility, especially organogenic soils, in which processes of mineralization of peat organic matter and related accumulation and use by plants of mobile nitrogen compounds and its leaching into groundwater occur with different intensity (Truskavetsky, 2010; Slyusar, 2019; Slyusar et al., 2020). Our studies show (Table 1) that the soil's content depended significantly on the crops grown and mineral fertilizers applied. The content of nitrate-nitrogen in the soil shows that it was accumulated most of all (290 and 324 mg per 1 kg of soil) in Giant miscanthus plantations; many of it was also accumulated in crops of annual row crop corn - 212 and 267 mg per 1 kg, much less under perennial grass crops (140 and 177 mg) and even much lower indicators were under tree crops.
We found the most intense peat mineralization under miscanthus and annual row crops and weakest - under poplars and willows. This is also evidenced by the degradation of linen fabrics carried out by our application method (Table 2). Analyzing the decomposition of tissue on average over three years, we found that the degradation of tissue in soil under scantlings was the greatest and was 36.6-38.5%, and the lowest - in soil under woody crops - 9.6-17.4% of buried tissue in the exposition. Thus, the results of these studies have shown that the creation of energy tree plantations on drained organogenic soils provides a significant reduction of mineralization of peatlands against growing annual crops and miscanthus on them.
The amount of potassium in the 0-30 cm layer under tree crops was 327-447 mg per 1 kg of dry soil, against the content under annual crops only 144 mg, i.e., less by almost 2-3 times. The annual biomass yields of willow trusses and poplar hybrids (Table 3) were 2-3 times higher than those of annual and perennial crops (5.7-9.9 t/ha of dry weight). The accumulation of biomass also spent more potassium component in almost the same amount.

Table 2. Degradation of linen fabrics depending on energetic crops and fertilizing in the drained organic soils of the River Supiy basin

Crops	Fertilizer	2018			2019			2020			Average mineralization, %
		Tissue weight, g		Mineralization, %	Tissue weight, g		Mineralization, %	Tissue weight, g		Mineralization, %	
		bb	m		bb	m		bb	m		
Almond-leaved willow	none	10.5	1.96	18.7	10.96	1.39	12.7	13.69	1.55	11.3	14.2
	K_{120}	10.6	3.09	29.1	11.59	1.48	12.8	13.49	1.39	10.3	17.4
Basket willow	None	9.8	2.69	27.4	11.31	1.87	16.5	11.29	1.38	12.2	18.7
	K_{120}	11.6	3.16	27.2	11.52	1.74	15.1	13.75	2.09	15.2	19.2
Gray willow	none	7.9	1.71	21.6	12.84	1.51	11.8	10.18	1.77	17.4	16.9
Toropogritskiy hybrid black poplar	None	8.4	1.08	12.9	11.35	1.19	10.5	13.32	1.28	9.6	11.0
	K_{120}	6.8	0.87	12.8	11.26	1.08	10.5	9.18	1.09	11.9	11.7
Hybrid Robusta poplar	None	8.9	0.59	6.6	9.32	1.29	13.8	11.42	1.23	10.8	10.4
	K_{120}	10.1	0.95	9.4	9.04	1.18	13.1	11.28	1.16	10.3	10.9
Poplar I-214	None	9.8	1.65	16.8	12.02	1.59	13.2	12.32	1.72	14.0	14.7
Giant miscanthus	None	10.5	4.63	44.1	11.93	5.03	42.2	9.8	3.78	38.6	33.4
	K_{120}	10.2	4.93	48.3	12.48	6.00	48.1	10.5	5.36	51.0	49.1
Perennial grasses of constant sowing	None	9.8	3.42	34.9	12.02	2.24	22.3	10.65	0.85	8.0	21.7
	K_{120}	10.7	3.88	36.3	10.94	3.91	35.7	13.4	2.36	17.6	29.9
Corn for grain	None	12.8	5.2	40.6	11.35	3.08	27.1	11.7	4.3	36.6	34.8
	K_{120}	11.8	5.0	42.4	10.6	3.40	32.1	10.9	4.2	38.5	37.7

bb – before burying, m - mineralized

In parallel with growing these crops for biomass, water consumption studies of bioenergy crops in water-balance lysimeters were conducted at the experimental station during the same period. We found that the willow in the third year of cultivation consumed more than 24 thousand m3 of water in terms of 1 hectare. At the same time, according to our data, water consumption by annual crops and perennial grasses in the same lysimeters in previous years was about 5-6 thousand m^3 per 1 ha (Slyusar, 1986). So, water consumption by woody crops was almost three times higher than by annual crops. If we subtract summer atmospheric precipitation, the amount of which in these years was about 4-5 thousand m^3, with a coefficient of their use of 0.7-0.8, then almost 20 thousand m^3 per 1 ha of water was raised by tree crops plants from groundwater. Undoubtedly, together with capillary water, various salts were transported from the underlying peat rock, which is a gleyed light loam enriched with various biogenic substances. The rock in the floodplains was mixed with sapropel, vivianite, ferrous and other substances, boggy compounds of potassium, calcium, phosphorus, nitrogen, and other elements.
So, plantations of tree crops provide movement of various salts from groundwater to surface soil layers and thus prevent and, to some extent, clean groundwater from biogenic substances, which in the winter-spring period flow down ditches into rivers, pollute river and groundwater and promote the overgrowth of water bodies by blue-green algae and different aquatic plants.
Thus, under the conditions of drained organogenic old-fallow soils, mineralization of organic matter and accumulation of mobile nitrogen in the active layer of soil under miscanthus plantations and annual crops (267-324 mg per 1 kg of dry soil) occurs intensively, while the lowest indicators had energy tree plantations (57-120 mg). At the same time, the content of mobile phosphorus and potassium was the highest in plantations of woody crops according to 105-172 mg and 224-462 mg, against

their content under miscanthus and annual crops, respectively 52-66 and 91-171 mg per 1 kg of dry soil, which was significantly affected by high total evaporation of woody crops plantations and input together with capillary water of biogenic substances from underlying rock rich in mineral compounds into the active soil layer.

Table 3. Influence of fertilizers on the crop yields (average for 2017-2019, t per 1 ha of dry weight)

Crop	Fertilizers		$HIP_{0.5}$
	Without fertilizers	K_{120}	
Almond-leaved willow	24.9	25.7	0.9
Basket willow	25.2	25.6	
Gray willow	12.3	12.8	
Toropogritskiy hybrid black poplar	30.0	30.3	0.8
Hybrid Robusta poplar	27.2	27.6	
Poplar I-214	25.4	27.4	
Giant miscanthus	16.5	25.2	0.9
Perennial grasses of constant sowing[2]	5.9	9.9	0.5
Perennial herbs of the first-year cultivation[2]	6.5	8.8	
Corn for grain[2]	5.7	7.7	0.4

Note 1 - content averages from four variants of miscanthus planting density; 2 - data of stationary experiment with crop rotations, which borders with planting energy crops.

The creation of woody (willow and poplar) energy plantations on drained old-fallow organogenic soils provides environmentally safe and efficient use of them prevents intensive mineralization of organic matter and contributes to a significant reduction of pollution of ground and river water by nutrients.

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