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*§ 9.2 AGROECOLOGICAL FEATURES OF THE USE OF ENERGY CROPS IN THE CONDITIONS OF UKRAINE*
(**Rytchenko A.,** Poltava State Agrarian University, **Rozhko I.,** Poltava State Agrarian University, **Kulyk M.,** Poltava State Agrarian University)

**Introduction.**Today all necessary preconditions are available for implementation of the bioenergy development programme in Ukraine. First of all, soil-climatic conditions which contribute to obtaining high yield of energy-intensive phytomass of energy crops. Secondly, the use of adaptive technologies for growing energy crops on marginal lands, improvement of the existing technologies, proper processing of phytoraw material and biofuel use in the fuel and energy complex will ensure the increase of bioenergy share in the overall energy structure of Ukraine. As a result, the reduction of non-renewable energy resources use, and increase of demand for alternative energy sources, which will contribute to development of the national economy in the future [1].

It has been established that Ukraine has a significant potential of biomass available for energy use, and almost all preconditions for the better use of plant residues for biofuel purposes such as production of solid, liquid and gaseous fuels [2]. In this scientific publication is considered a systemic approach to solving the problems of energy security and ecological in Ukraine through balanced agricultural development with the view for the bioenergy sector.

**1. Biological features of energy crops**

Today, the main priorities of the new industry – bioenergy are the search for the ways to reduce the cost of various types of biosources, the development of new technical and economic decisions, as well as the formation of the necessary infrastructure for more efficient use of plant energy resources and the processing of their phytomass for the production of liquid (bioethanol, biobutanol), gaseous and solid biofuel (granules, briquettes, etc.).

In order to implement the bioenergy development program in Ukraine, all the prerequisites are available, first of all – the soil-climatic conditions that contribute to the high yield of energy-intensive phytomass of energy crops. Secondly, the use of adaptive cultivation technologies on marginal lands of bioenergy crops, improvement of existing, appropriate processing of phytosterol as well as biofuel use in fuel and energy complex will provide the increase in the share of bioenergy in the overall energy structure of Ukraine and significantly reduce the energy dependence of our country. And as a result, reducing the use of non-renewable energy sources, against the backdrop of growing demand for alternative energy sources, which in the long run will contribute to the development of the national economy and the growth of population welfare [3].

The Energy Strategy of Ukraine until 2030 [4] predicts a dynamic increase in the use of biomass energy in 2015 to 5 million tons of conventional fuel (tonnes of conditional fuel), which is 2.5 % of the total energy consumption, and in 2030 – up to 20 million tonnes of conditional fuel or up to 10 %.

In addition, the Law of Ukraine "On Alternative Energy Sources", as amended [5, 6], defines the main principles of state policy in the field of alternative energy sources, among which are the following: increasing production volumes and consumption of energy, produced from alternative sources for the purpose of economical spending of traditional fuel-energy resources and reducing Ukraine's dependence on their import by restructuring production and rational energy consumption by increasing the share of energy from renewable sources.

In addition, in the biomass electricity sector, the situation changes with the introduction of a new method of calculation according to the "green" tariff for electricity, produced from renewable energy sources. This calculation procedure is highlighted in the Law of Ukraine “On Amendments to the Law of Ukraine” on Electricity “regarding the promotion of the use of alternative energy sources” [7], and the Regulation “On Approval of the Procedure for Establishing, Revision and Termination of the Green Tariff for Subjects economic activity” [8]. All this, in our opinion, determine the relevance of the chosen research direction.

A large number of scientific works have been devoted to the study of energy crops in our country: M. V. Roik, V. L. Kurylo, M. Ya. Humentik [9], O. M. Hanzhenko [10], D. B. Rakhmetov [11], D. B. Rakhmetov and A. M. Verhun [12], H. H. Heletukha, T. A. Zhelezna, O. V. Tryboi [13], H. S. Honcharuk, S. M. Mandrovska [14], Elbersen H. W., Kulyk M., Poppens at all. [15] and others.

Among the energy crops in Ukraine, the most widespread are: switchgrass, willow, miscanthus, poplar (their lifetime is 10 – 15, sometimes up to 30 years old), agro- technical measures for their cultivation do not require significant expenses, harvest in winter or spring, using conventional agricultural machinery [16, 17, 18, 19]. Along with these crops, Arundo reed [20 – 21], Sugar sorghum and perennial sorghum, Indiangrass and Big bluestem are of scientific interest too.

Also, energy crops have the following different uses (Fig. 1).

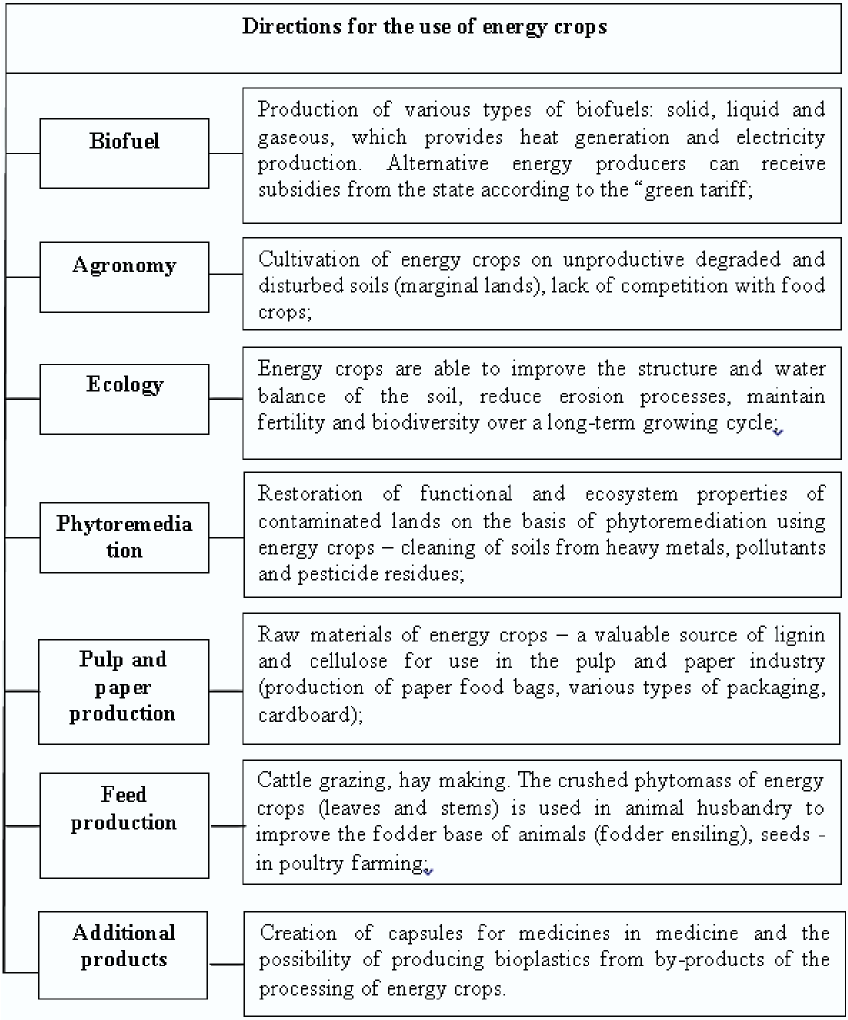



***Fig. 1.** Directions for the use of energy crops, according to the data from Kalinichenko et al., 2017 [3]*

But the detailed study of the morphological and biological characteristics of these crops, the potential of their yield and energy efficiency was not paid proper attention (Fig. 2).

**Switchgrass**
*(Panicum virgatum L.)*

**Sorghum perennial, Columbus grass**
*(Columbus Grass, Sorghum almum Parodi)*

**Indiangrass**
(*Indiangrass, Sorghastrum nutans (L.)*

**Big bluestem**
(*Big Bluestem, Andropogon gerardii Vitman*)

***Fig. 2.*** *Photos of energy crops*

H. M. Kaletnik in his monograph [22] has systematized the scientific and methodological and organizational and economic fundamentals for the development of the biofuels market, the creation and development of a market for energy crops used as raw materials for the production of biofuels, technical and technological characteristics of the production of biofuels from raw materials of plant origin, and also provided an economic assessment of their use by the agro-industrial complex of Ukraine. The author's generalization of world trends in the development of the biofuels market from raw materials of plant origin, allowed to develop the economic substantiation of the prospects for further development of the Ukrainian biofuel market.

The study of energy crops, with the exception of certain publications, mainly concerns the crop and energy potential, the possibility of obtaining biofuels from their biomass, without considering the botanical and biological characteristics of these crops, and the possibility of their zoning in the soil-climatic zones of Ukraine for the fuller realization of the potential of crops from purpose of obtaining the maximum yield of biofuels from biomass plants.

**2. Material and method of theoretical research**

To solve this problem, based on the available information and the results of our own work, we give the generalized morphological and biological characteristics of plants, illustrative materials of energy crops from the family of Poaceae. The estimation of potential of their productivity, energy and biofuel productivity as well as possibility of cultivation in different soil-climatic zones of Ukraine has been performed.

In research the following methods have been used: methods of conducting research [23, 24], determinants, library catalogs, albums [25, 26, 27], atlases [28], reference books [29] and special methodological recommendations [30, 31]. The energy value of raw materials was determined on an ISO 200 calorimeter. The energy productivity of plants was determined on the basis of heat capacity and yield of phyto raw materials, taking into account the methods [32].

**3. Agrocological features of energy crops cultivation**

M. V. Roik with coauthors shares this point of view [33] and affirms that energy crops are perspective and profitable plants for cultivation on low productive soil.

Switchgrass (Panicum virgatum),silver grass, (Miscanthus giganteus) and energy willow are the most widespread energy crops in Ukraine [34].

1. Switchgrass is a warm-season, perennial grass, forming strong root system and vertical hollow stems of different colours growing up to 3 metres tall. The inflorescence of this grass is panicle. Reproduction is by seed and from clonal offsets of the rhizomes. Switchgrass provides yield up to 18 t/ha of dry mass with energy capacity of 17 MJ/kg [35].

2. Silver grass (Miscanthus giganteus) is a warm-season, perennial grass, forming strong root system and vertical stems growing up to 5 metres tall. Vegetative reproduction. Yield is 20 – 30 t/ha of dry mass with energy capacity of 18 – 19 MJ/kg [36].

3. Energy willow is a ligneous and shrubby plant of Salicaceae species, having a rapid growth. Willow does not make great demand on the soil and moisture.Vegetative reproduction. Yield is up to 30 t/ha of dry mass with energy capacity of 18 – 20 MJ/kg [37].

According to natural and economic factors, Ukraine belongs to the countries with favorable conditions for both food and energy security. The country has a significant potential for creation of stable market for energy crops and using their raw materials for the biofuel industry [38].

The territory of Ukraine is divided into three natural and climatic zones: Polisia, Forest-steppe and Steppe. These zones have specific soils, climate, temperature regimes, rainfall and crop production technologies.

The main types of soils in Polisia are sod-podzolic soils with different degrees of podzol and mechanical composition. Climatic conditions are characterized by moderately continental climate. The annual precipitation varies from 550 to 650 mm.

The main types of soils in Forest-steppe are clear-gray loess, gray loess, dark gray podzol, chernozem podzol, typical chernozem, meadow chernozem and meadow soils. Climatic conditions are diverse (higher average annual air temperature). The annual rainfall varies from 450 to 550 mm.

The main types of soils in Steppe are chernozem and chestnut, common meadow black soil, meadow-chestnut, meadow and saline soils. Climatic conditions are continental. Annual precipitation varies from 350 to 450 mm.

Distribution of potential of energy crops across the territory of Ukraine is quite diverse from 9 thousand t.o.e. (Uzhgorod oblast) to 736 thousand t.o.e. (Zhytomyr oblast). Zhytomyr, Chernihiv, Kyiv, Odessa, Zaporizhzhia, Kherson oblasts and Crimea are characterized by the highest energy crops potential (more than 400 thousand t.o.e.), Table 1.

*Table 1*

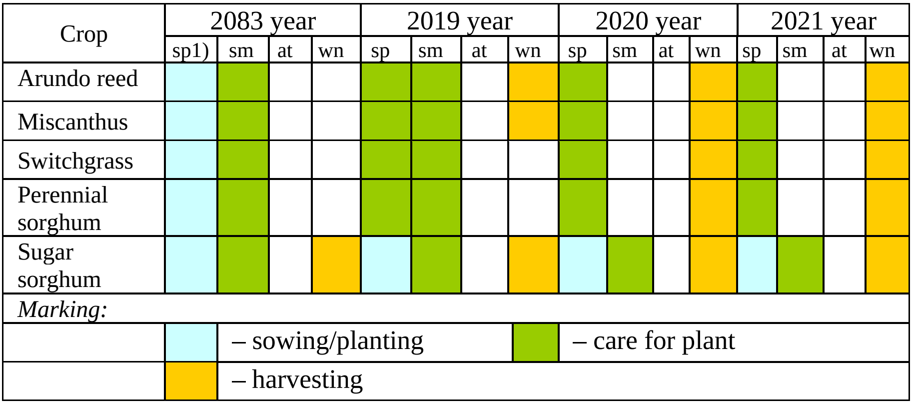
**Potential of energy crops in Ukraine**

| Oblast | Available potential, thousand t.o.e. (tons of oil equivalent) |
|---|---|
| Zhytomyr | 736 |
| Chernihiv | 546 |
| Kyiv | 417 |
| Poltava | 405 |
| Others | less 400 |

*Source: author's development.*

The comparative characteristics of energy crops in the period of biomass supply make it possible to state that the proper crop management approach, the dry matter yield (raw material for biofuels: solid, liquid and gaseous) is from 10 to 15 t/ha, can be obtained for a long period of time from August-September of the previous year to February-March of the next year.

The synthesis of the research results allowed to compare the period of energy crops biomass obtaining (Fig. 3).



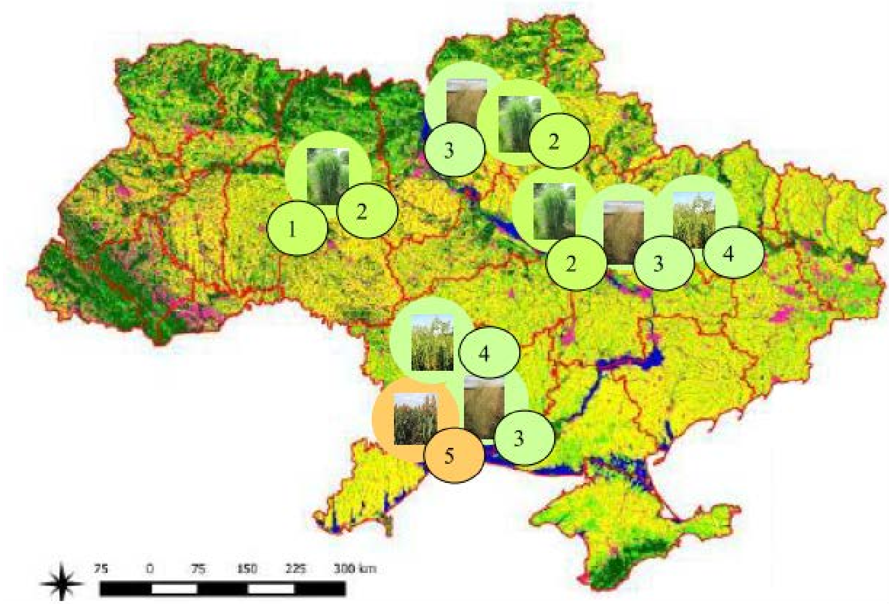

[1)]Note: sp – spring period, sm – summer period, at – autumn period, wn – winter period.

***Fig. 3.*** *The synthesis of the research results allowed to compare the period of energy crops biomass obtaining*

*Source: author's development.*

In accordance with agro-climatic zoning in Ukraine, there are zonal features of selection and cultivation technology of agricultural and energy crops. In connection with this, an attempt has been made to allocate places of cultivation of cereal energy crops on the territory of Ukraine, taking into account the biological characteristics of plants.

Fig. 3 shows the theoretical distribution of places for cultivation of energy crops in the territory of Ukraine (Fig. 4).




*Note:* 1 – arundo reed; 2 – miscanthus; 3 – switchgrass; 4 – perennial sorgo; 5 – sugar sorghum.

***Fig. 4.*** *The theoretical distribution of places a cultivation of energy crops in the territory of Ukraine*

*Source: author's development.*

Taking into account the morphological and biological features, the ratio of plants to the temperature regime and the amount of precipitation during the growing season, it is advisable to place the energy crops of the Poaceae family in Ukraine as follows: Arundo reed and switchgrass – Polissia zone, giganteus Miscanthus, millet-like, perennial sorghum and sugar sorghum – Forest-Steppe, millet-barley, perennial sorghum and sugar sorghum – Steppe Ukraine. In addition, different crops of the genus Miscanthus can also be grown in compliance with the relevant irrigation conditions in the Steppe zone.

**4. Ecological features of energy crops cultivation**

Replacing fossil fuels with biomass results in global environmental benefits such as reduced greenhouse gases emissions. However, not only the use of biomass can lead to benefits for the environment, but also the biomass production. This paper will show that when traditional annual food crops are replaced with perennial energy crops on Ukrainian arable land, negative environmental effects, such as erosion, nutrient leaching and the emission of greenhouse gases, may be reduced. Similar conclusions have been drawn in earlier studies concerning, for example, perennial energy crop production in the USA (see e.g., Tolbert [39]; McLaughlin and Walsh [40]; Hort et al. [41]; Grigal and Berguson [42]; Bransby et al. [43]). Energy crop systems can also be used to purify municipal waste, thus decreasing negative impact on the community. Furthermore, the content of heavy metals in the soil could be reduced through cultivation of short-rotation forest. These environmental benefits can increase the energy crops value thereby affecting future market conditions for biomass.

In this research, environmental changes are identified and quantified while traditional food and forage crops are replaced with perennial energy crops on Ukrainian arable land. This paper, being based mainly on a literature sources review, represents Part I of the analysis, which is complemented by a second part in which the economic evaluation of the environmental changes is carried out. Thus, this paper is a background to the second paper, which contains a more integrating synthesis. The purpose of the overall study is to analyze how energy crop cultivation in Ukraine could be located and managed in order to maximize environmental benefits. Neither environmental effects arising from replacing fossil fuels with biomass nor environmental benefits from the reduced use of fossil fuels in perennial energy crop cultivation, in comparison to annual crop cultivation, are included in this study. These benefits have already been analysed in earlier studies. The significance of the environmental benefits depends on geological and geographical conditions, while population density affects the amount of municipal waste that can be recycled on energy crop cultivation. Thus, the environmental impact has been analysed on a regional basis and then aggregated to a national level. Since agricultural practices, the load of anthropogenic pollutants and waste generation, are changing over time, the potential impact of energy crop cultivation also changes over time. The time during which environmental advantages could be achieved has been estimated.

Energy crops covered in this analysis are short-rotation forest (Salix) and energy grasses (reed canary grass). In the north of Ukraine, only reed canary grass is assumed to be grown for energy purposes as the climatic conditions are not suitable for Salix cultivation [44]. This situation can, however, change in the future if more frost resistance Salix clones will be available. The energy crop cultivation is assumed to be geographically equally distributed on current arable land used for perennial forage and annual food crop production [45]. Today, about 40 % of Ukrainian arable land is used for the production of perennial forage crops, mainly ley, while about 60 % is used for annual crop production. When perennial energy crops replace perennial forage crops (in Ukraine normally clover-grass pastures), the environmental changes are to slight and therefore neglected, except when the impact is particularly caused by the cultivation of Salix, e.g. reduced wind erosion and cadmium removal. In annual crop cultivation, which in Ukraine is dominated by grain cultivation, fertilization is to be undertaken annually, the average dose of chemical nitrogen (N) fertilizer is about 140 kg N/ha year, and the average dose of chemical pesticides is about 1 kg active ingredients ha. Reed canary grass cultivation, harvested once a year, extends over 10 years, while Salix cultivation, harvested every fourth year, extends over 25 years. The biomass yield of Salix is on average, 10 tonnes of dry matter/ha year, and of reed canary grass, 6.5 tonnes of dry matter/ha year [46].

Cultivation methods in agriculture are changing, as well as the load of anthropogenic pollutants and the generation of waste. Thus, the time during which environmental impact could be sustained has been estimated. This estimation is based on physical and chemical properties of the soils, environmental goals for future agricultural practices, recycling of waste, reduction of anthropogenic emissions, and prognoses for the possibility of achieving these goals.

The term "environmental change" or "changed environmental impact" is used here in a broad sense. Effects on soil, water, air, flora and fauna, as well as the recirculation and purifying of municipal waste, are involved. Environmental changes when perennial energy crops replace annual crops identified in this paper have been divided into six categories: 1) greenhouse gases, 2) nutrient leaching, 3) heavy metals, 4) soil fertility and erosion, 5) municipal waste, 6) biodiversity.

The aesthetic impact of short-rotation forest on the landscape has not been considered here. Depending on the nature of the surrounding landscape, and the design of the cultivation, Salix cultivation can cause both positive and negative effects on the landscape [47]. Neither the impact of Salix on tile drainage is considered, which could lead to expenses. There is a great risk of damage to the tile drainage when Salix is cultivated, due to the deep Salix roots [48]. If energy crops are to be cultivated in fields with new tile drainage systems, energy grass should be grown in preference to Salix.

The informative measure of land-use efficiency is the level of transportation service that can be provided from a hectare of land. Taking into consideration the rate of biomass feedstock production per hectare, the efficiency of converting the feedstock into a biofuel, and the efficiency of using the biofuel in a vehicle, one can estimate the vehicle-kilometres of travel that can be provided by a hectare of land. Among all biofuels, starch-based first-generation fuels give the lowest yield of vehicle-kilometres/hectare/year, since only a part of the aboveground biomass is used as input to a biofuel production facility.

By this land-use efficiency measure, sugar-based fuels of the first-generation are about twice as good as starch-based fuels. Second-generation fuels, because they utilize much more of the available aboveground biomass than first-generation fuels, can provide an improvement of 50 per cent or more in land-use efficiency over sugar-based first-generation fuels [49].

The comparison does not provide any information, regarding the net energy balance of biofuel production, the associated net lifecycle greenhouse gas emissions, any economic considerations. These additional factors, must also be considered while evaluating any particular biofuel system.

Environmental benefits from the reduced use of chemical pesticides in perennial energy crop cultivation, in comparison to annual crop cultivation, is restricted to be included only in the category “biodiversity”. No analysis of the reduced risk of, for example, ground water pollution has here been carried out due to lack of data.

Greenhouse gas emissions from arable land can be reduced in three different ways when annual crops are replaced with perennial energy crops, through (I) accumulation of soil carbon (C) in mineral soils, (II) reduced carbon dioxide ($CO_2$) emissions from organic soils, and (III) reduced nitrous oxide ($N_2O$) emission caused by the use of fertilizers. Changes in the emissions of other greenhouse gases are estimated to be small and are therefore neglected.

The effectiveness with which greenhouse gas emissions (GHGs, including $CO_2$, $CH_4$, and others) can be avoided using biofuels is related to the amount and carbon intensity of the fossil fuel inputs needed to produce the biofuel, as well as to what fossil fuel is substituted by biofuel use.

A proper GHG accounting considers the full life cycle of the biofuel, from planting and growing biomass to conversion of the biomass into biofuel, to biofuel combustion at the point of use. (In the case of vehicle application, this full life cycle analysis is sometimes referred to as a "well-to-wheels" analysis.) If the harvested biomass is replaced with new biomass growing year-on-year at the same average rate at which it is harvested, then $CO_2$ is being removed from the atmosphere by photosynthesis at the same rate at which the already-harvested biomass is releasing $CO_2$ into the atmosphere – a carbon-neutral situation. However, typically some fossil fuel is consumed in the course of biomass producing or converting or delivering the biofuels to the point of use, resulting in net positive GHG emissions on a life cycle basis. These emissions will offset to some degree the emissions that are avoided when the biofuel is used in place of a fossil fuel [50].

There could also be net GHG emissions associated with converting land from its current use to use for biomass energy feedstock production. The net emissions might be positive if existing forests are removed in order to establish energy crops. The net emissions might be negative if perennial energy crops (which can build soil carbon) are established, replacing annual row crops that were being grown on carbon-depleted soil. Emissions associated with land use change can be significant, but they greatly depend on the local factors. Therefore, GHG emissions associated with such land use changes have not been considered in the study. There are a lot of scientific works on GHG life cycle analyses (LCAs) of biofuels.

Higher GHG savings with biofuels are more likely when sustainable biomass yields are high and fossil fuel inputs to achieve these are low, when biomass is converted to fuel efficiently, and when the resulting biofuel is used efficiently. Conventional grain-and seed-based biofuels can provide only modest GHG mitigation benefits by any measure (per mega joule of fossil fuel displaced, per v-km driven, or per hectare of land use) and will be able to provide only modest levels of fuel displacement in the long term in any case due to the relatively inefficient land use associated with these fuels [51].

More efficient land use in mitigating GHG impacts can be achieved in the longer term by dedicated high-yielding lignocellulosic energy crops. Decades of experiment with development of food crop yields, together with recent experiments with developing lignocellulosic energy crops, suggest thatgreat yield can be expected (probably with lower inputs per tonne of biomass produced) with concerted development efforts. Today cconsiderable private sector investments in research and development of energy crops, accelerate progress in improving yields. Assuming high yields are sustainable and acceptable from biodiversity and other perspectives, land requirements to achieve GHG emission reductions with biofuels will be reduced. There is also the possibility for some by-product $CO_2$ to be captured (for long-term underground storage) during the process of making biofuels, especially via thermochemical conversion. This could lead to negative GHG emissions for a biofuel system. Proposals have also been made for thermo chemically co-processing coal and biomass to make carbon-neutral liquid fuels by capturing and storing some $CO_2$ produced during the conversion process [52].

It is necessary to note that biomass can be converted into heat or electricity as well as into liquid fuel. GHG emissions per unit land area that are avoided in this way may be greater than when making liquid fuel. However, for electricity or heat production, a variety of renewable resources is available (hydro, solar, geothermal, wind, etc.). Biomass is the only renewable source of carbon, which makes it the only renewable resource for producing carbon-bearing liquid fuels.

The rate of change in soil carbon depends on the rate at which organic matter is added to the soil and the rate at which erosion and biological oxidation remove the organic matter from the soil [53]. These mechanisms are substantially reduced if soil tillage is reduced or eliminated, which is the case when annual crops are replaced with perennial energy crops. Also, the input of organic matter from litter and roots to the soil is high in energy crop production. In an established Salix cultivation, 4.5 – 10 tonne dry matter/ha is recirculated yearly, of which about two thirds are litter and one third is roots [54]. Only a minor part, however, is converted into stable humus containing, on average, about 60 %, as most of the organic residues are decomposed within period of a few weeks up to a year [55].

Results of field trials show that a vertical gradient of soil carbon is developed after a few years of Salix cultivation, with a higher carbon content in the top soil. No significant changes in the total content of soil carbon have yet been recorded, as these changes take place over a long period of time. Long-term field trials with leygrass in Ukraine, which could be comparable to Salix regarding changes in soil carbon, show an increased level of humus equivalent to 30 – 40 tonnes C/ha, compared with food crops after 30 years [56]. To some extent, this difference could be explained by changes in cultivation practices, as the depth of fertilizaion is probably greater now than in the 1960 s, causing a higher dilution of soil carbon in food crop cultivation with frequent fertilizaion. Therefore, the change from annual to perennial crop production leads to a lower increase in soil carbon content than the results of field trials presented above indicate.

An annual carbon accumulation in mineral soils of 0.5 tonne C/ha is assumed here, over a period of about 50 years. After that, the humus level is estimated to reach a new, higher, steady state of about 1 – 1.5 percentage points higher than today. This estimate is, however, uncertain and must be verified by long-term field trials. Changes in soil carbon storage also vary for different soils and locations due to soil texture, drainage, base status and climatic parameters [57]. The proportion of the total Ukrainian arable land where energy crop cultivation could increase the soil carbon level is estimated to be 55 %. This is equivalent to the area covered by mineral soils (which amounts to about 90 % of the total arable land on which annual crops are cultivated today. At present, about 60 % of Ukrainian arable land is used for annual crop production [58]. On the remaining 40 %, where perennial forage crops are cultivated, there is no increase in the soil carbon level.

As a comparison, Ranney and Mann [59] estimate that short-rotation plantations in North America increase the soil carbon inventories (excluding litter and roots) by about 10 tonne/ha over 20 – 50 years.

When organic soils are cultivated, soil carbon is released by oxidation leading to a subsidence in ground level. In an initial phase when an organic soil is drained, a lowering of ground level is also caused by compression and shrinking. The carbon loss is higher in annual crop cultivation than in perennial crop cultivation due to more frequent soil tillage. Results of Ukrainian investigations [60] show the subsidence rates are greatest when the crops are potatoes and carrots, 2–3 cm/year, followed by grain 1–2 cm/year, and permanent pasture 0.5 cm. Based on these results, a change from cultivation of annual crops to perennial energy crops reduces the subsidence rate from 2 to 1 cm/year. This is equivalent to about 7 tonne C/ha year, as the density and carbon content of cultivated organic soils in Ukraine are about 200 kg/m$^3$ and 35 %, respectively [61]. This theoretical calculation has, however, not been verified by field trials [62]. Salix thrives best on organic soils consisting of fen peat (Cavex). If the organic soil is composed of bog peat (Sphagnum), however, Salix is not a suitable crop due to the low pH of the soil. Thus, bog peat soil is more suitable for the cultivation of reed canary grass.

The reduced $CO_2$ emission from organic soils when cultivating energy crops lasts, on average, 80 years after which the peat layer will have been dissipated by biological oxidation. A rough estimate is that the thickness of the peat layer, which can vary greatly both within a field and between different fields [63, 64], varies from a few decimeters up to two meters in Ukrainian organic soils, with an average of about 80 cm. The proportion of arable land where energy crop cultivation could decrease the $CO_2$ emission by about 7 tonne C/ha yr, is 5 %. This is equivalent to the area covered by organic soils (which amounts to about 9 % of the total arable land, on which annual crops are cultivated today.

Nitrous oxide emission from arable soils is induced by the use of fertilizers. Loss of fertilizer nitrogen (N) as $N_2O$ varies from almost zero up to 2 %, due to differences between soils, fertiliser type, climate and land management practices [65, 66]. Since energy crops have a lower nitrogen demand than food crops, on average, about 50 kg N/ha year [67], a change in land use from food to energy production allowed to reduce the emission of N2O. Regression analyses by Bouwman [68] show a statistically weak correlation between N2O emission and application of nitrogen fertiliser. A rough estimate from this correlation is, however, that growing perennial energy crops instead of annual crops on mineral soils will reduce N2O emission by, on average, 0.3 kg N2O-N/ha year. A similar estimate has been made by the National Ukrainian Environmental Protection Board [69]. This reduction is equivalent to about 40 kg C relative to the Global Warming Potential (GUP) of CO2 over 100 years [70].

When perennial energy crops replace annual crops, the nutrient leaching is reduced. Nutrient leaching from annual crop cultivation could also be reduced by using energy crop cultivations as buffer strips along open streams. Growing perennial energy crops instead of annual food crops reduces the risk of water pollution through leaching and runoff, due to reduced input of fertiliser, longer growing season, soil cover all year round, and a more extensive root system [71, 72]. Nitrogen (N) leaching from short-rotation forest and ley production, for example, is estimated to be 30 – 50 % and 75 % lower, respectively, than from grain production [73, 74]. This benefit will be greatest on coarse-textured sandy soils, as the nitrogen leakage from these soils is, on average, twice as high as from fine-textured clayey soils [74]. The average nitrogen leaching from arable land varies between 13 and 48 kg N/ha yr in southern and central Ukraine, where the highest losses are for south-west Ukraine [75].

The period of time during which energy crop cultivation will significantly reduce nutrient leaching is estimated to 25 years or more. Current measures in agriculture aiming to reduce nutrient leaching are not sufficient of attaining stated environmental goals. Also, a structural change towards a more even geographic distribution of crop production and animal production takes time. According the National Ukrainian Environmental Protection Board [76, 77], uneven geographic distribution of crop production and animal production is a major reason for the problems associated with nutrient leaching and eutrophication.

The annual accumulation of cadmium (Cd) in Ukrainian arable soils is equivalent to 0.20 – 0.25 % of the total content of cadmium in the soil, which has increased by around 33 % during this century [78]. One result of this cadmium accumulation is that in southern Ukraine, the cadmium content in grain harvested on intensively cultivated farmland sometimes exceeds the limit of 0,1 mcg Cd/kg grain, proposed by WHO/FAO [79].

Energy crop cultivation is being tested in large-scale trials in Ukraine as vegetation filters for municipal waste water, for example, in the municipalities. Energy crop cultivation can also brutalized for the treatment of landfill leachate and sewage sludge.

Interest in vegetation filters for municipal waste water treatment, as a complement to the conventional treatment methods, has increased due to the problem of marine eutrophication.

Low-input agriculture generally provides a number of promising practices that can help improve the social-ecological sustainability of biomass production while maintaining economic feasibility [80]. Here, a key parameter is the ratio between on- and off-farm inputs. According to low-input agriculture, the use of on-farm inputs should be maximized and off-farm inputs minimized.

**Conclusions**

1. According to the soil-climatic conditions of Ukraine, energy crops vary widely. This is due to their origin, biological characteristics, adaptive reactions at the introduction of plants and agrotechnical requirements for cultivation.

2. The conditions of the Forest-Steppe and the Steppe are more suitable for switchgrass, perennial sorghum and sugar sorghum. In Polissia, the soil-climatic conditions most correspond to biological characteristics and are favorable for the cultivation of arundo cane and miscanthus giganteus.

3. The environmental benefits from large-scale introduction of energy crop production in Ukraine can be substantial, as the negative environmental impact from current agriculture practices and municipal waste treatment can be significantly reduced. The carbon dioxide emission from organic soils through biological oxidation of the organic matter, for example, can be significantly reduced (by about 7 tonnes C/ha year) when annual crops are replaced with perennial energy crops. The greenhouse gas emmisions from changed land use on mineral soils, through soil carbon accumulation and reduced nitrous oxide emission, is around 1:10 and 1:100, respectively, of that through changed land use on organic soils. As a comparison, the reduction of carbon dioxide emissions due to the lower input of fossil.

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