CHAPTER «AGRICULTURAL SCIENCES»

MORPHOMETRIC INDICES OF PLANTS, BIOLOGICAL PECULIARITIES AND PRODUCTIVITY OF INDUSTRIAL ENERGY CROPS

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Abstract. The section of the monograph contains a substantive research on the peculiarities of productivity formation of industrial energy crops as an alternative source for biofuel production. The classification and areas of energy crops usage have been given. Their botanical and biological descriptions as well as morphometric indices of plants from vitatel family (*Poaceae*), mallow family (*Malvaceae*), spurge family (*Euphorbiaceae*) and buckwheat family (*Polygonaceae*) have been provided. Research object is morphometric indices of plants and the regularities of formation of biomass productivity of energy crops: switchgrass (*Panicum virgatum L.*), miscanthus giganteus (*Miscanthus × giganteus J.M. Greef & Deuter ex Hodkin*), perennial sorghum (*Sorghum almum Parodi.*), sida hermaphrodita (*Sida hermaphrodita Rusby*), rumex (*Rumex patientia L. × Rumex tianshanicus A. Los.*), castor-oil plant (*Ricinus communis L.*). *Methods.* The research was conducted by the laboratory and field experiments in the conditions of the central forest-steppe of Ukraine. Monograph method (generalization of scientific publications of domestic and foreign authors);

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abstract-logical method (determining the essence of research, identifying factors affecting productivity of energy crops); statistic method (calculation of the smallest significant difference in order to establish distinguishing features between the variants, a correlation-regression analysis of crop productivity dependence on the morphometric plant indices) were used in the research. *Results.* A detailed morphometric description from the separation of biofuel part of energy crops, their biological characteristics and productivity potential have been provided. Actual productivity of switchgrass, miscanthus giganteous, perennial sorghum, sida, rumex and castor-oil plant has been determined by the experimental way. Correlation dependencies between morphometric indices and productivity of the studied energy crops have been identified. This enabled to establish the very plant biometric indices affecting biomass productivity of energy crops to the greatest extent. *Conclusion.* It has been determined that the most of energy crops are perennial crops that form tall-growing stems with a strong phytomass, hardy to environmental conditions, disease-resistant and have a fibrous root system. Productivity of the vitatel family representatives highly depends on the height and density of stems; plants from the mallow family and spurge family form productivity due to the plant height and the number of branches per plant, and the largest biomass of rumex is determined by the height of a stiffen peduncle.

1. Introduction

The study of the peculiarities of productivity formation of industrial energy crops, as an alternative source for biofuel production is becoming increasingly important. This is connected with the dynamics of non-renewable natural resources depletion, violation of the environmental balance, obtaining of additional product and profit as well as sustainable development of territorial communities. That is why, investigation of morphometric plant indices, productivity potential and improvement of the cultivation technology of energy crops is an issue of the day. Liquid, solid and gaseous biofuels that can be converted into heat, mechanical and electrical energy are produced from the top vegetative mass of these crops after appropriate processing. Obtaining alternative energy in the future will reduce the usage of such non-renewable energy resources as coal, oil and natural gas [1].

Such energy crops as perennial sorghum, miscanthus giganteus, switchgrass and others which are capable to provide high yields throughout a perennial cultivation cycle on marginal lands are of high interest for solving this pressing problem [2]. Possibility of using plant residues of castor-oil plants, which is grown mainly as an oil crop is also very interesting. Particular attention is paid to the new energy crops such as sida and rumex.

In our country, marginal lands are expanding year after year, that is connected with an anthropogenic impact on them. Therefore, there is a need to reduce the usage of non-renewable energy sources by growing energy crops on these lands and involving a new alternative to the fuel and energy complex of Ukraine, which simultaneously contributes to a solution of the environmental problems of soils [3].

Further, complicated study of the peculiarities of formation of energy crops, which are planned to be grown on marginal lands is a relevant problem as well.

2. The literature review

Today, most of the energy crops are already well-studied as phytoenergy ones, the technology for their cultivation and use of biomass is partly developed [4; 5].

In addition, information on the peculiarities of energy crops productivity formation, depending on the crop morphometric parameters, is currently not sufficient for more complete understanding of the biomass yields formation regularities. The percentage of the used part of energy crops for biofuel purposes, depending on their morphological structure as well as establishing a connection between crop biometric indices and productivity need to be clarified. Other issues are not fully embraced in the scientific literature.

In Ukrainian forest-steppe conditions on the basis of morphological and biological peculiarities of castor oil plant and switchgrass, long-term research was conducted to study the seed yields formation peculiarities of these crops. The authors found out that the castor oil plant and the switchgrass have the same type of reaction to the weather conditions. Thus, under optimal conditions during the vegetation period (HTC is close or more than 1), an increase in biometric and seed productivity was observed, and vice versa, it is confirmed with certain correlation dependencies. It has been statistically proved that the castor oil plant forms larger seed yield, depending on the length and the number of generative organs, and switchgrass is based on the panicle length and its amount per crop. In general, according to 5-year experiment results, the significant influence of air temperature and rainfall on the formation of crop productivity elements was found. These factors are decisive for castor oil plant and switchgrass yield growth [6].

Studying switchgrass morphological structure, T. O. Shcherbakova and D.B. Rakhmetov found out that crops P. *virgatum produce* the following types of shoots: vegetative-generative short- and long-roots (laid as on the underground part of the parent shoot in the zone of the “arc of the truncated internodes” as in the basis of its aboveground part); vegetative underground and aboveground (formed in the axils of the underground part in the parent soots, as well as in the axils of the stem leaves); generative aboveground (developed in the axils of stem leaves). The authors describe in detail the morphological parameters and morphogenesis peculiarities of regeneration, sleeping and reserve buds. It is established that the length of the internodes correlates with the length of the leaf blades and petiole parts of the leaves; the maximum value of the mentioned parameters is observed in the middle part of the stem zone [7].

It has been established that one of the main features of the switchgrass is the ability to effectively use favourable conditions for growth and development and accumulate a large amount of dry matter during the growing season. But at the same time, plants need appropriate requirements for growing conditions, especially for heat and moisture [8].

Perennial sorghum forms a strong aboveground vegetative mass for a perennial growing cycle due to the quantitative plant indices, taking into account the weather conditions of the growing season and the age of plants [9].

High growth indices are distinctive for plants of all species and forms Miscanthus. By the height and length of the leaf the Miscanthus × giganteus is the leader, by the diameter of the stem, the number of internodes on the sprouts, the width of the leaf blade – M. sinensissamples. M. sahchariflorus plants have the smallest growth indicators. Growth indices were the highest at the end of the growing season. The largest variety of leaves (by size, color, etc.) is inherent in the forms of M. sinensis. The basic morphological characteristics of the panicle (form, length, width, number of branches in the panicle, their size and shape, etc.) in different species and forms of Miscanthus are determined. According to the long-terms results of the authors’ research, perspectives of introduction of the Miscanthus genus representatives in Ukraine as a new high-productive energy plant have been proved [10].

In Europe, it has been determined that miscanthus shoots on the plantations of the first cultivation year can reach two meters or more, and each next year – up to four meters, with the simultaneous increase in the number of stems that grow with rhizome [11].

M. Hryshko National Botanical Garden of the National Academy of Sciences of Ukraine as a selection institution is a leader in Ukraine for the selection of many crops, including energy ones, one of which is a perennial sida, that forms a high stem strength, has a significant biomass productivity, nutritional quality and ecological plasticity to the cultivation conditions [12].

Castor oil plant growth and development, even as an annual crop, are determined by the tendency of the species to continuous growth and development, which at the end leads to the inconsistency ripening of the crop. Herewith the forms of the Chinese subspecies are characterized by relatively rapid pace of development and weak vegetative growth; for other subspecies – powerful growth and a slow pace of development is distinctive [13].

The manifestation of the morphological features of castor oil plants depends on the influence of external conditions. This is especially possible to be traced to vegetative organs, changes in the number, shape and size of which affect the viability of the plant. Even weak changes in external conditions, such as humidity or temperature, can cause a noticeable reaction [14].

It has been established that the accumulation of vegetative mass and dry matter in the castor oil plants is 41.6 t/ha and 12.4 t/ha respectively, in the terms of energy productivity is 210.8 GJ/ha. Moreover, the period of the largest biomass accumulation for this crop is the end of August, and during the next two months, castor oil plant gradually loses its accumulated biomass yield to 10.4 t/ha [15].

Rumex is a new crop, created in the new crops department of M. Hryshko National Botanical Garden in the National Academy of Sciences of Ukraine. This crop is suitable for integrated use as a food, forage, energy, technical and medicinal plant [16].

The authors, on the basis of their own research, found out that under the southern Steppe conditions, the pace of rumex linear growth deeply depends on the weather conditions: the plant height – on air temperature and rainfall, the leaf area increases from the first to the fourth year of vegetation, and the productivity of the green and dry biomass – on the nutrition area and the plant age [17].

Other scientists found out that the most productive crops on peat soils in the humid zone of Ukraine (on average, for five years) were corn –

19.1 tons per 1 hectare (325 GJ/ha), sorghum silage – 13.9 tons per 1 hectare (215 GJ/ha), castor oil plant and mallow –10,6 and 9,5 t per 1 hectare (209 and 147 GJ/ha); miscanthus – 28.9 tons per 1 hectare (491 GJ/hectare), artichoke – 26.6 tons (452 GJ/ha),silphium – 24.3 tons (413 GJ/hectare), and sida– 23.0 tons per 1 ha (391 GJ/ha) [18].

The energy crops research in Ukraine is mainly aimed at investigation of the yield and energy potential, the possibility of obtaining biofuels from their biomass, without taking into account the morphometric, botanical and biological characteristics of these crops. Therefore, the chosen direction of research, embracing the study of morphometric crop parameters, biological characteristics and productivity potential of industrial energy crops is relevant and requires detailed study and justification.

3. Research material and methods

The research on the peculiarities of biomass production of energy crops was conducted in the conditions of the central part of forest-steppe during 2015-2017. The following energy crops: miscanthus giganteus, switchgrass, perennial sorghum, sida, castor-oil plant and rumex were the material for the experiment. The general statements of the research methodology, approved methodological recommendations for the preparation of an area and cultivation of crops, in particular energy crops as well as scientific methods for field and laboratory researches were used [19].

According to the recommendations of domestic [20] and foreign scientists [21] it has been determined and recommended energy crops plantations to be laid in pre-prepared areas that are unsuitable for agricultural production. In this experiment, the following requirements have been satisfied: a collection of energy crops was laid on marginal lands with the following agrochemical characteristics: humus content is less than 2%, the content of nitrogen, phosphorus and potassium is lower than the average, pH is more than 7.0.

Generally-accepted and specially developed research methods [22; 23], determinants, library catalogs, albums [24; 25], reference books [26] and special methodological recommendations were used in the research [27].

4. Research results

4.1. Classification and usage areas of energy crops

Energy crops are woody and herbaceous plants cultivated in order to get raw materials that the various usage areas (Figure 1).

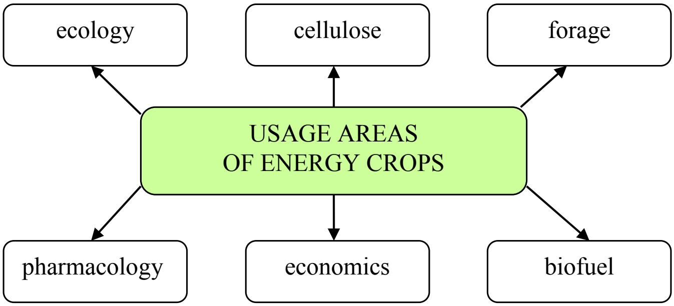


Figure 1. Usage areas of energy crops biomass

We studied the following energy crops: vitatel family (*Poaceae*) – switchgrass, miscanthus giganteus, perennial sorghum; mallow family (*Malvaceae*) – sida hermaphrodita, or sida forest, Viginian malva; spurge family (*Euphorbiaceae*) – castor-oil plant; buckwheat family (*Polygonaceae*) – rumex.

Energy crops are capable to improve the structure and water balance of the soil, reduce erosion processes, and maintain fertility and biodiversity for a long-term cultivation cycle. Upon the termination of energy crops plantation usage, it is possible to turn the unproductive lands into agricultural lands, taking into account a balanced fertilizing system. Besides, energy crops is a CO2-neutral plant that "reduces the greenhouse effect" and minimizes global warming trends.

The problem of reduction of potential danger to human health as a result of a change in the type of land use can be solved by restoring the functional and ecosystem properties of the contaminated lands on the basis of phytoremediation with the help of energy crops – soil purification from heavy metals, pollutants and pesticides residues.

The raw materials of lignin-cellulose energy crops are a valuable source for cellulose and paper industry and pharmacology. These are the production of paper food packets (polyethylene substitute), various types of packing, cartons, which will reduce using wood resources, as well as capsules for drugs.

Grinded green phytomass of many energy crops (leaves and stems) is used in poultry and livestock breeding in order to improve animal forage supply (silaging).

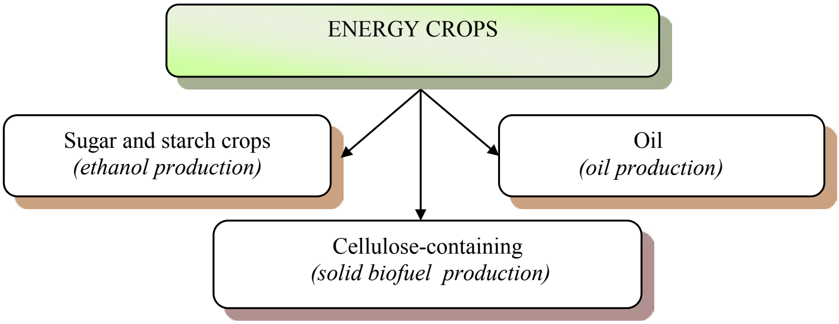


Figure 2. Division of energy crops according to the usage areas of biomass

Biomass of energy crops is an energy-intensive raw materials (16-17 MJ / kg) for the production of various types of biofuels: solid (pellets, briquettes), liquid (bioethanol, diesel biofuel) and gaseous (biogas).

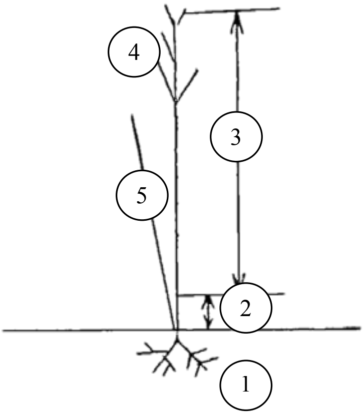
As a whole, there are different usage areas of energy crops with getting additional product that increase economical effect of its phytomass production.

Aboveground vegetative mass (phytomass) is mainly used as a raw material for the production of various types of biofuels. Therefore, energy crops are divided according to the usage ares of their biomass (Figure 2).

4.2. Morphometric indices of energy crops

The height of stubble , the stem length, the number of branches per stem, the number of leaves per plant and the length of the generative part of plants are the main morphometric indices of energy crops involved in the biomass formation that is removed or left in the field. General view and morphological structure of energy crops are given in figure 3-8.

Switchgrass (*Panicum virgatum L.*) is a perennial grass with a life cycle up to 10-15 years. It can grow up to 100-150 to 210-250 cm with 12-14 to 30-35 productive trailings per the plant. Plants can be straight and slightly curved. The number of metameres on the stem is from 3 to 7 and in some forms this number is up to 9. Leaf blade is 50-60 cm long, width is 11-14 mm on average. Panicle is flat, oval, pyramidical and cob-like. Panicle length is 30-40 cm, width is 20-30 cm. Seeds are divided into three groups according to weight of 1000 seeds: a low weight group – up to 1.5 g,



A – General view **B** – Morphological chart of a plant

Figure 3. Switchgrass *(Panicum virgatum L.)*

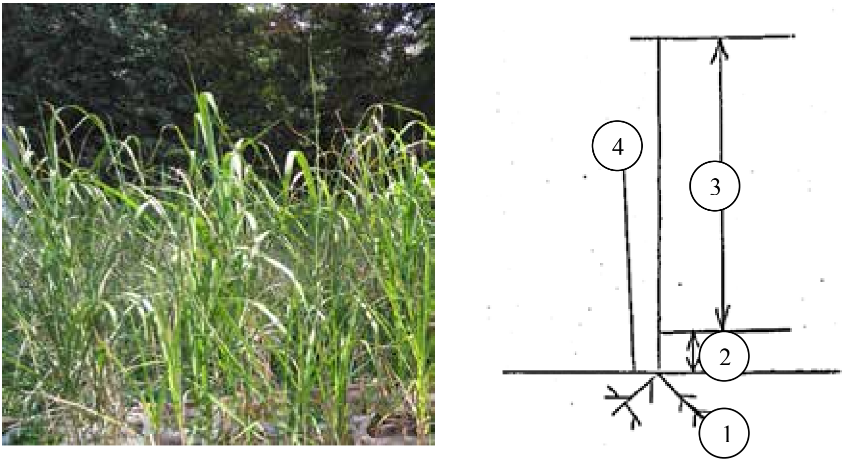
Note: 1 – root system (fibrous, forms small rhizomes), 2 – height of cutting, 3 – biofuel part of the plant, 4 – inflorescence (panicle), 5 – new shoots.

an average weight group of up 1.5-1.8 and a large weight group – more than 1.8 g. Perennial rhizomes can be splitted into 8-25 (up to 80) parts, each of them is 5-7 cm long in vegetative reproduction.

Unlike most perennials, switchgrass goes a full cycle of development cycle(from seed to seed) throughout the first vegetation period. The crop completes intensive vegetation in the third decade of August – late October, depending on the genotype. The intensive plant regrowth begins after overwintering, in early spring. The phase of stem elongation begins in the second decade of July. Flowering period is from the third decade of July to the first decade of August. Ripening period is late September -the middle of October. Vegetation period lasts about 175-185 days [11].

Yield of aboveground phytomass in the period of panicle apparence is 42-64 t/ha, in the flowering period is 42.7-70.2 t/ha; dry weight is 10-15 t/ha; seeds is 500-600 (sometimes up to 1000) kg/ha. Energy productivity of plants is 40-60 (up to 80) Gcal/ha.

Miscanthus giganteus is a tetraploid hybrid of the Chinese miscanthus (*M. sinensis* Anderss.) and sugar flower miscanthus (*M. sacchariflorus* (Maxim.) Benth. A perennial grassy plant with a C4-scheme of photosynthesis.



A – General view **B** – Morphological chart of a plant

Figure 4. Miscanthus giganteus

(*Miscanthus* × giganteus J.M. Greef & Deuter ex Hodkin)

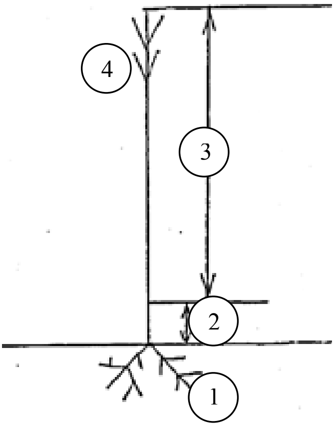
Note: 1 – root system (fibrous, forms medium and large rhizomes), 2 – height of cutting, 3 – biofuel part of the plant, 4 – new shoots.

Plants reach a height of 220–310 (may reach 450-500) cm. The number of shoots in the bush is 10-15 (up to 70). The stem is straight and rounded. The diameter of the stem is 12-25 mm. The number of leaves on the stem is 11-15 pieces, the width is 2.2-2.9 cm, and the length is 93-102 cm. The panicle has a spindle-shaped, cone-shaped or elliptical shape and reaches a length of 30–33 cm. Plants have loosely-bunched type of tillering. The number of rhizomes in one plant is from 18 to 37 pieces, their length is 10-15 cm.

Regrowth of branches in spring begins in the second half of April, tillering begins in late June, stem elongation – late August. The vegetation completes in the phase of panicle appearance (often in the stem elongation phase) in the first half of October. The life cycle of plants lasts 15-20 years.

The yield of green phytomass is from 60 to 150 t/ha, dry weight is 10-15 (to 32) t/ha. The energy productivity of plants is 67-84 (up to 130) Gcal/ha.

Perennial sorghum (*Sorghum almum* Parodi.) belongs to the Poaceae family. The plant has a height of 230–300 cm. The main stem and all



A – General view **B** – Morhpological chart of plant

Figure 5. Perennial sorghum (*Sorghum almum Parodi***)**

Note: 1 – root sysrem (fibrous), 2 – height of cutting, 3 – biofuel part of the plant, 4 – inflorescence (panicle).

the side shoots on the top are finished with a panicle. Leaves are long-lanceolate, 60-80 cm long and 3-5 cm wide. The number of leaves per plant varies from 18 to 26 pcs. The leaves with their base cover the half of a stem. Inflorescence is panicle of 40-45 cm long. Seeds are elongated, brownish black. Weight of 1000 seeds is 8.5-9.0 g. The root system is well developed and penetrates into the soil to a depth of 2.0-2.5 m. During drought, it is able to develop the secondary roots. The optimal seeding time is the 1st and the 2nd decade of May, when the soil warms up to a depth of 10 cm to 12-14°C. Seed germination is 75-80%. The optimal temperature for plant growth and development is 18-25 0C above zero.

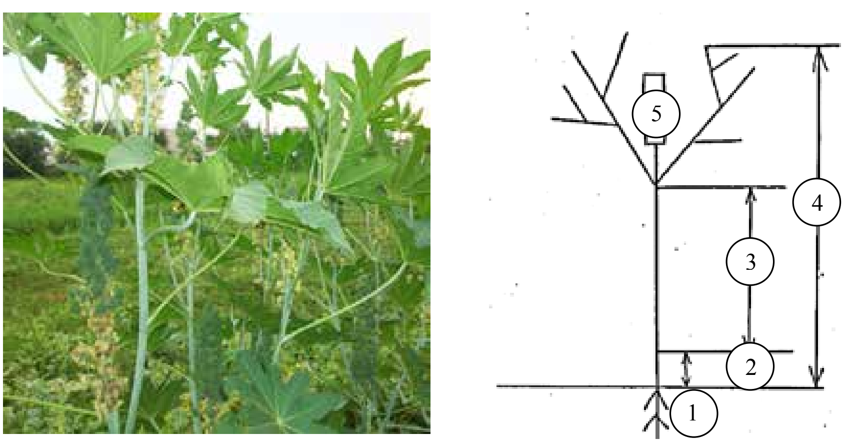
The yield of green mass at the beginning of panicle formation provides 30–35 t/ha, in the flowering period is 45-50 t/ha, and during the period of fruiting is 65-75 t/ha, seed is 1.5-1.7 t/ha. The yield of dry phyto raw materials is 11-14 t/ha. The energy value is 3750-3810 kcal/kg.

Sida (also called hermaphrodite or Virginia malva), lat. *Sida hermaphrodita Rusby* is a perennial plant from the mallow family that forms a strong, tall (up to 4 m) aboveground vegetative mass. The leaves are simple, but palmately cleft into 3 to 7 lanceolate lobes. The inflorescence is a cluster

A – General view **B** – Morhpological chart of plant

Figure 6. Sida *(Sida hermaphrodita Rusby)*

Note: 1 – root system (top-root), 2 – height of cutting, 3 – biofuel part of the plant, 4 – inflorescence (cluster).



A – General view **B** – Morphological chart of the plant

Figure 7. Castor-oil plant *(Ricinus communis L.)*

Note: 1 – root system (tap-root), 2 – height of cutting, 3 – biofuel part of the plant, 4 – total plant height, 5 – inflorescence (cluster).

with 11-15 flowers. Sida produces small white flowers in July-September period. Fruit are light-brown capsules and each has 6-9 carpels. Seeds are irregular roundish, bud-like, oval, gray-brown. Weight of 1000 seeds is 3.30-3.90 g. The plant is frost and winter resistant, late-ripening, resistant to diseases and pests.

Yield of dry biomass is 20-22 t/ha.

The energy productivity of plants is 390 GJ/ha.

Castor oil plant is a species in the spurgy family (*Euphorbiaceae*). There is a great diversity of castor-oil plant forms. They differ by appearance, biological demands and farm peculiarities.

In Ukraine castor-oil plant is an annual grass that can reach the size from 0.5 to 5 m with strong root system. The root system consists of thick primary root and 3-6 large lateral roots with numerous tillers which form smaller roots. Primary root of castop-oil plant penetrates into soil to 2-4 m depth. However, late-ripening forms have stronger root system than early-ripening ones. Moisture deficit results in root growth into the depth. In wet years roots grow closer to the surface using rainfall moisture.

Castor-oil plant stem is hollow, geniculate, change in colour with 15-18 or more internodes. The faster ripening form the less internodes it has. The most fast-ripening forms have stem with 5-6 internods and the most late-ripening varieties have more than 18 internods. Primary branches grow from the main stem, the secondary branches grow from the primary and the third branches grow from the secondary ones. Castor-oil plant does not develop branches of other orders in Ukraine.

The number of branches changes according to the nutrition area, weather, soil and other conditions. Plants almost do not branch out on the dense crop areas, in hot summer or on low-productive soils. On the contrary, plants branch out well in humid years and on fertile soils.

Stems, leaves, petioles and unripe fruit capsules can be covered with slight or thick waxy bloom and there are forms where waxy bloom is absent.

The plant is leafy. Leaves are petioled, alternate, except two first – opposite. Leaf blade is peltate with 7-11 lobes and with toothed segments.

Castor-oil plant flowers are heterosexual, small, in terminal panicle-like inflorescences. There are clusters of the main stem (central), the first order and etc. Clusters of both male and female flowers are bunched in groups – tsimas. They are spirally arranged on the inflorescence caudex. Each tsima has the central flower, flower of the first order and etc. Tsimas with male flowers are placed at the botom of inflorescence and with female flowers – at the top of inflorescence. There are forms providing dioecious.

The fruit is a three-lobed capsule. Each lobe contains one seed. Castor-oil seeds are shiny beans of different colour, size and form with smooth shine surface. Large sized seeds with length from 22 to 15 mm, middle-sized seeds with length from 14 to 9 mm and small-sized seeds with length from 8 to 5 mm are distinguished. Weight of 1000 seeds is from 70 to 1000 g depending on the botanical form and cultivation conditions.

Castor-oil seeds contain poisonous substance – toxic albumin which, depending on the dose, can be fatal for both animals and humans. Alkaloid ricinine also has poisonous properties. Castor-oil plant is highly demanding to warm weather, light and moisture.

The yield of dry biomass of castor-oil plant by-products can be up to 10.0-14.0 t/ha. Energy productivity of plants is 145 GJ/ha.

Rumex is a perennial plant from the buckwheat family (*Polygonaceae*), a highly productive hybrid of English sorrel and Tien-Shan sorrel. It grows up to three meters in height, characterized by a rapid increase in the aboveground vegetative mass: during a day plants give an increase of 7-8 cm.

A – General overview **B** – Morhpological chart of the plant

Figure 8. Rumex *(Rumex patientia L. × Rumex tianshanicus A. Los.)*

Note: 1 – root system (fibrous), 2 – height of the sectiony, 3 – biofuel part of the plant (stiffen pendicle), 4 – inflorescence (panicle).

Plants in the first year of vegetation do not form generative shoots, but leaves form a strong basal rosette at the root. Plants form peduncles which are becoming stiffen in the second year of vegetation. Leaflets of rosette are large, fleshy, placed on long, grooved petioles. Root cap in the first year of vegetation reaches 18-20 mm in diameter. The root is taproot, branched, dipped into 1.5-2.0 m.

In the second year, in spring, while snow melting, rumex restores vegetation and begins to regrow. During this period of time it is used as a vegetable crop. In the stage of shooting -the beginning of panicle formation, the first mowing is done, in 1-2 months – the second one with a height of plants of 120-130 cm.

From the second and following growing years, in spring several generative shoots (from four to six) develop simultaneously, and they until the vegetation completion period grow up to 190-250 cm along with inflorescence. Panicle length is from 70 to 130 cm. Flowers are small, mostly hermaphrodites, pink. Fruit is a three-sided achene. Weight of 1000 carpels is about 4.0-4.6 g, Weight of 1000 seeds is 2.5-3.6 g.

Rumex is a highly plastic, hardy, drought-, cold- and winter-resistant plant, which withstands frost up to -3 ... -5°C both in spring and in autumn. The sum of effective temperatures (above + 5°C) from the beginning of spring regrowth to the first mowing for greens is 50-60°C, for forage is 323-384°C, for seed ripening and biofuel purposes is 800-830°C.

Rumex is resistant to soil salinization. It is able to from can carry up to 300-375 g of salt from 1 hectare every year.

Yield of the aboveground mass is 10-15 t/ha of dry biomass per year, productivity period is 6-8 years, energy output is 150-160 GJ/ha, or it is 15-16 MJ/kg.

4.3. Formation of energy crops productivity

Productivity of energy crops is formed at the expense of the biofuel part of plants. Biofuel part is a part that is removed from the field, it is a part of the stem with inflorescence or without it.

Perennial sorghum and miscanthus provide the highest productivity of the biofuel part of plants – more than 200 g/running metre, switchgrass, castor-oil plants, sida and rumex provide much less productivity – 188.0; 164.1; 140.2 and 108.0 g/running metre, respectively (Figure 9).

The comparative characteristics of energy crops by the period of biomass supply allows to assert that phytomass yield (raw materials for biofuels: solid,

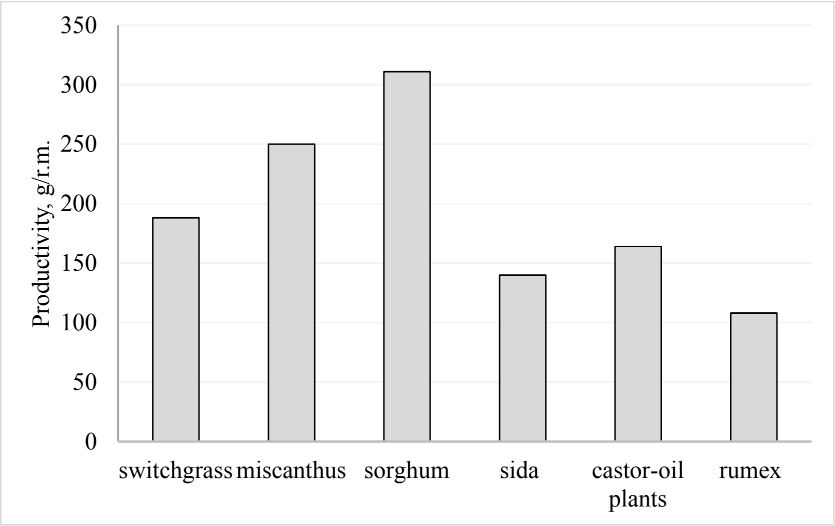


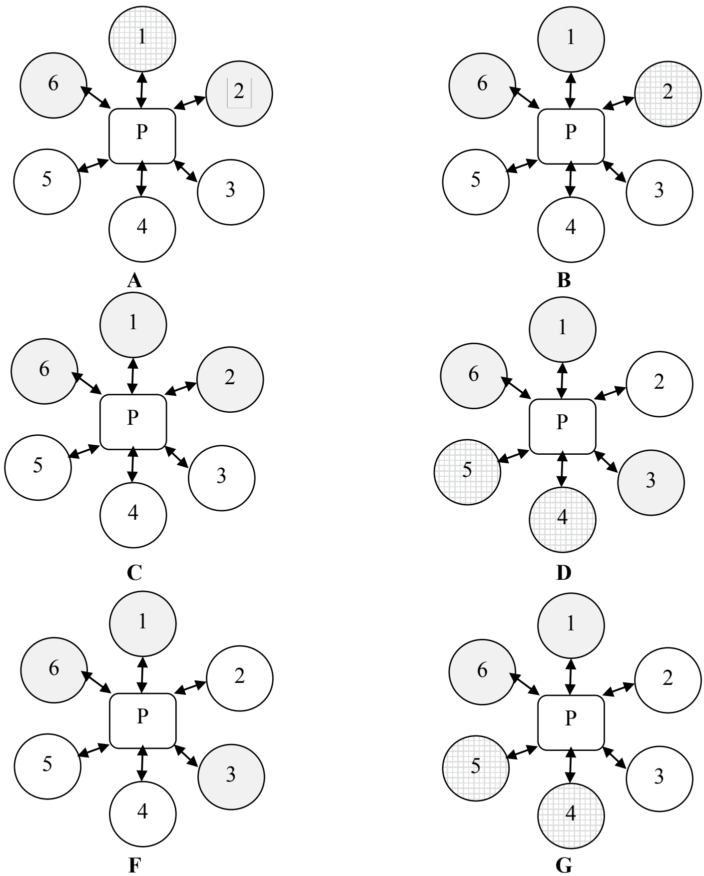
Figure 9. Productivity of energy crops, on average during 2015-2017

liquid and gaseous) can be constantly obtained during a long period of time – since August-September period of the previous year to February-March period of the next year while applying a proper crop management approach.

On the basis of correlation-regression analysis, it has been determined that quantitative indices of the vegetative part of plants significantly favour to the formation of energy crops productivity.

In order to establish the correlation between biometric plant indices and productivity (P) of energy crops for accounting, the following quantitative indices were used: 1. PH – plant height (см), 2. NS– number of stems per plant (pieces), 3. NB – number of branches per the stem(pieces), 4. NL – number of leaves per the stem (pieces), 5. TNL – total number of leaves per plant (pieces), 6. DMC – dry matter content (%).

It has been determined that energy content and biomass yield of all these crops depend on dry matter content in biomass. In addition, it has been established that productivity of switchgrass, miscanthus and perennial sorghum deeply depends on height and density of plant stand; sida and castor-oil plants form productivity due to the plant height and the number of branches on it, and the height of stiffen peduncle determines the largest biomass of rumex. This is confirmed by the correlation coefficients between morphometric indices which have a weak, middle or strong correlation with productivity of a particular energy crop and are given in the form of correlation pleiade in figure 10.



Note: * - correlaton is significant at 5-% level of value.

	- grey background, correlation coefficient is more than 0.7 (strong correlation)
	- other background, correlation coefficient is 0.3…0.7 (middle correlation)
	- white background, correlation coefficient is less than 0.3 (weak correlation)

Figure 10. Correlation dependencies between quantitative indices and productivity of energy crops (A – switchgrass, B – miscanthus, C – perennial sorghum, D – sida, F – castr-oil plant, G – rumex), 2015-2017

It has been established that perennial sorghum productivity significantly depends on the height (r 0.91) and density of plant stand (r 0.74).

The yield of miscanthus giganteus depends on the height of the plants by 79% at the correlation coefficient of r 0.89 and on the number of stems by 82% at the correlation coefficient of r 0.91. Herewith, the regression equations will have the following form $y = 1.56 + 0.07 \times x$ (plant height and yield) and $y = 10.48 + 0.18 \times x$ (number of stems and yield).

It has been determined that switchgrass yield depends on the plant height by 24% at the correlation coefficient of r 0.49 and on the number of stems by 76% according to the correlation coefficient of r 0.87. The regression equations will have the following form: $y = 3.84 + 0.06 \times x$ (plant height and yield) and $y = 8.16 + 0.02 \times x$ (number of stems and yield)

The height of plants (r 0.77) and the number of branches (r 0.81) greatly affect the productivity of castor-oil plants. Sida provides productivity at the expense of the biofuel part of the plants (r 0.74) and the number of branches per plant (r 0.69). Rumex productivity significantly depends on the number of leaves in the leaf-rosette (r 0.70) and the lengths of the inflorescence shoot (r 0.75).

5. Conclusions

1. Among the energy crops that are being studied in the conditions of the forest-steppe of Ukraine as a plant raw material for biofuel production, the largest number is the vitatel family representatives: switchgrass, miscanthus giganteus, perennial sorghum. These crops are characterized by a perennial life cycle, tall-growing stems, fibrous root system, and also they are hardy to the environment conditions and disease-resistant.

2. According to the morphometric indices, which determined the largest yield of biofuel part of the plants, the following energy crops have been distinguished: perennial sorghum and miscanthus – more than 200 g/running metre, or more than 20 t/ha of biomass, much less dry biomass productivity is provided by castor-oil plants, switchgrass, sida and rumex. It also depends on dry matter content in biomass at the time of harvesting, this index for energy crops varied within the range from 65.4 to 78.3%.

3. Productivity of the vitatel family representatives (perennial sorghum, miscanthus giganteus, switchgrass) depends on height and density of plant stand to a greater extent; plants from the mallow family and family (sida and castor-oil plants) form productivity due to plant height and the number

of branches per plant, and the height of stiffen peduncle determines the largest biomass of rumex(representative of buckwheat family).

Prospects of the future researches will imply determination of peculiarities of productivity formation and quality of seed and planting material of these energy crops.

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