IMPACT OF PLANT BIOMETRIC CHARACTERISTICS ON SEED PRODUCTIVITY OF CASTOR-OIL PLANT AND SWITCHGRASS DEPENDING UPON WEATHER CONDITIONS OF THE VEGETATION PERIOD IN THE FOREST-STEPPE OF UKRAINE

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Abstract. The article has demonstrated the necessity of investigating new, alien crops such ascastor-oil plant (Ricinus communis L.) and switchgrass (Panicum virgatum L.) as a raw material for production of biofuel and by-products for different fields of industry. The detailed description of plant morphology, and practices regarding increase of seed germination ability of the studied crops have been given. Solid literature overview has been made and attention has been emphasized on the up-to-date of the research of castor-oil plant and switchgrass seed productivity. Expanding of cultivation area enables to provide farmers with seed material as well as processing industry with raw material. In future this will permit to obtain seed material, plant biomass for energy purposes and technical oil of high quality in order to satisfy requirements of strategic fields of industry.

Research object is the morphological and biological peculiarities and seed productivity of castor-oil plant and switchgrass depending on quantitative indices of plants considering weather conditions of the vegetation period.

Methods. Methods of multi-year research in the forest-steppe of Ukraine are standard for the zone of these crops cultivation and special methodical recommendations have been used as well. The area of seeding plot of land was 54.0 м², the area of accounting plot of land was 50 м², experiment

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repetition is four time. Allocation of plots of land in the field is random. Observations and analyses have been applied according to the appropriate research recommendations. Statistical processing of the research results have been done by the analysis of variance as well as correlation and regression analysis, applying licensed computer programme Statistica–6.0.

Results. Switchgrass and castor-oil plant response to the environmental conditions has been defined and this enables to allocate these crops in certain soil and climate zones of Ukraine reasonably and choose the ideal elements of the cultivation technology. This will permit to work out farm operations for the development of conditions close to favourable for plant growth and development and providing high productivity of phytomass and seed.

It has been determined that studied crops have similar responses to the weather conditions. Under optimal conditions during the vegetation period (hydrothermal coefficient near or more than 1.0) increase of biometric characteristics, seed size and seed productivity has been recorded and vice versa. Established correlation dependencies have proved this factor ($r > 0,70$). Statistically proved that castor-oil plant provides higher seed productivity (to 2.68 тt/ha) depending on the length and number of clusters per the plant and switchgrass provides seed productivity depending on the length and number of panicle per the plant (to 0,93 t/ha). It has been also defined that seed productivity has close correlation connection with seed yield that is determined by biometric characteristics of the reproductive organs.

Conclusion. Considerable impact of air temperature and precipitation on the formation of crop productivity elements has been established according to the results of five-year experiment. Impact of air temperature and precipitation is determinative for switchgrass and castor-oil plants yield and productivity. It has been found that increase of precipitation as well as growth of air temperature is favourable for castor-oil plants yield but much drier weather of the vegetation period is better for switchgrass yield.

Taking into consideration research results according to biometric characteristics of plants and seed productivity depending on weather conditions, castor-oil plant can be recommended to cultivate on farms in the central forest-steppe of Ukraine in order to get technical oil of high quality and switchgrass is recommended to be used for biofuel production and energy generation.

1. Introduction

Today more thorough investigation of alien crops is increasingly demanded because of weather conditions changes, increase of temperature regime, frequent droughts and necessity of introducing new crops in order to get extra profit. Castor-oil plant and switchgrass are distinguished among the new crops which have scientific and practical importance and require detailed study of seed formation peculiarities to satisfy farm producers needs.

Castor-oil plant is an oil crop that is getting incresing influence over the economy year in year out in view of science and technology advancement. Taking in the fact that at the beginning of the past century the castor oil was mostly known in medicine, and now it is in great demand in many industries – automibile, machine engineering, pait-varnish and chemical ones [1].

Castor-oil seeds depending on the variety and cultivation conditions accumulate 50-55% of oil (castor or ricin one) that belong to the group of non-drying ones. This oil is sticky, slightly dissolvable in petrol and other organic solvents, does not hardened at low temperatures (12-18 °C below zero) and burns at high temperatures (300-3100C above zero). These properties make castor-oil an excellent oil material crop and it is used in different fields and directions [2].

Switchgrass is a drought-resistent, long-years standing crop that has simplified cultivation technology with minimal fertilizers applied and irrigation absence. The lesser irrigation and fertilizers applied means reduction of energy consumption that in turn means the lesser costs and emission of greenhouse gases are. Moreover, the crop is not soil demanding and no competitor to food crops.

Fuel obtained out of switchgrass raw material is used for producing solid (fuel pellets, bars) and liquid biofuel-cellulose ethanol. Besides using for biofuel, the grass mentioned above has a whole lot advantages and wide range of applications.

Switchgrass is used in construction, paper production, greening, animal feeding and effective environment pollution soil purification as well (phytoremediation). Above-mentioned crop is used as good grazing weed for animals (in spring), and haymaking process (in summer). Switchgrass does have a significant influence on lowering erosion processes over worn-out clay pits, coil pits, sand dunes, dams and other man-contaminated soils. The crop is suitable for wind-resistant greenery as well [3].

Switchgrass betters nature biodiversity, is being a natural habitat for many species of small animals and birds, diversity of insects provided them with shelter and nutrition. Switchgrass accumulates a significant mulching layer over its long cycle of life(fallen leaves, plant stems) that in addition to moisture increases the mixture of organic substance in soils that are not enriched with useful substances [4].

2. Morphological and biological characteristics of castor-oil plant

Castor oil plant (Ricinus communis L.) is a species in the spurgy family. There is a great diversity of castor-oil plant forms. They differ by appearance, biological demands and farm peculiarities (figure 1).

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 thich 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 and lateral roots to 1.5-2 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 secondaryones. 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. Petioles are of different length (15-45 cm), smooth with the colour of the stem. Leaf blade is peltate with 7-11 lobes and with toothed segments. Different botanical forms have different sizes of leaves. Plants are divided into large-leaved, small-leaved and middle-leaved ones according to the leaf

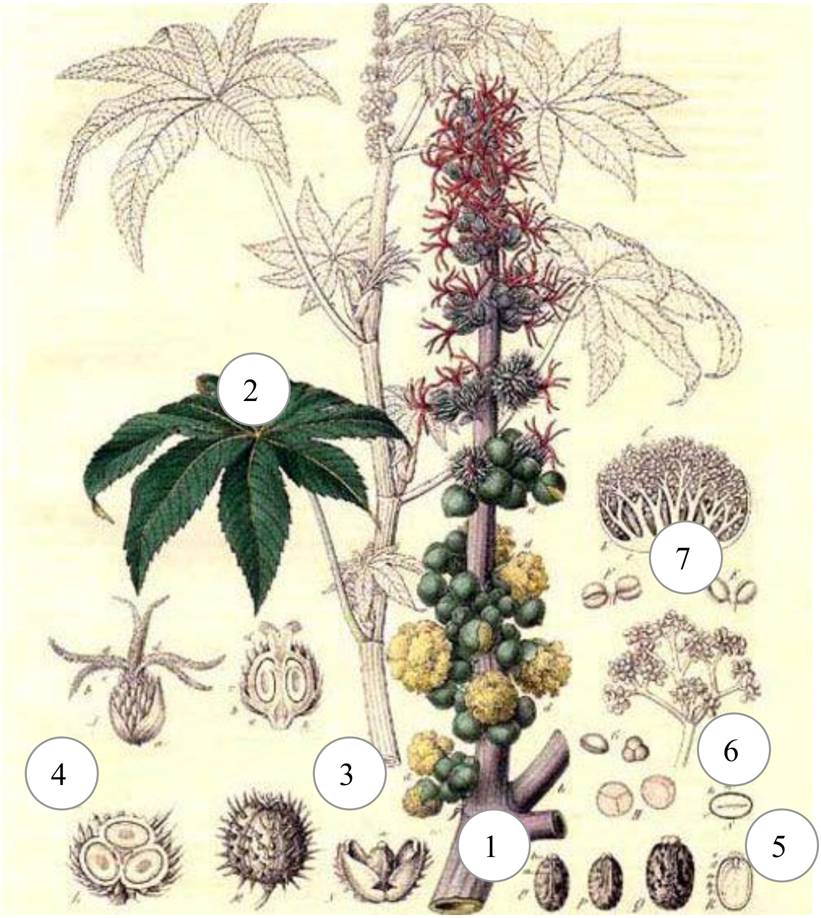


Fig. 1. Morphological structure of castor-oil plant (Ricinus communis L.).

1 – inflorescence; 2 – leaf; 3 – stem; 4 – fruit; 5 – seeds; 6 – the male flowers; 7 – the female flowers.

size of the middle layer. Green forms have green leaf blade, whereas other forms have fallow young leaf and mature leaf with green and purple ribs [5].

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 bottom of inflorescence and with female flowers – at the top of inflorescence. There are forms providing dioecious plants not depending on weather conditions.

The fruit is a three-lobed capsule. Each lobe contains one seed. Capsules are oval, elongate, spherical and of different sizes. Capsule size depends on the botanical castor-oil form, place in inflorescence, and inflorescence place itself. Capsules are smaller at the top of the central raceme and on the lateral racemes.

The external cover of the unripe capsule can be smooth, wrinkled and spiny. The capsules are green, dark-green, yellow, pink, red, dark-red and purple.

Capsules of some forms split out forcibly ejecting seeds, whereas others do not. Splitting can be strong, moderate and weak. Varieties grown in Ukraine have capsules which do not split out or split out moderately

Forms of castor-oil plant clusters are conical, narrow-cone, cylindrical, widely cylindrical and oval. Clusters are very long when the whole fruit system is occupied by capsules, long when capsules occupy 2/3 of the fruit system, of middle size when 1/2 of the fruit system is occupied and short when capsules occupy 1/3 or less of the fruit system length. Cluster length is measured by the distance from the bottom to the top capsule.

Castor-oil seeds are shiny beans of different colour, size and form with smooth shine surface. They are differentiated by background colouring and mosaic. Background can be grey, blue-grey, light-brown, dark-brown, light-red, dark-red. Mosaic colouring can be white, light-grey, pinkish, light-brown [6].

Forms of seeds are egg-shaped, ellipsoid, bean-like. Some botanical forms at the end of mature seed havea warty appendage called the caruncle. The caruncle is hyghly important for corcle nutrition and turns into dry husk [7].

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. Mass of 1000 seeds is from 70 to 1000 g depending on the botanical form and cultivation conditions. The mass of small seeds is 160-290 g, mass of middle seeds is 290-350 g and mass of large seeds is

350-1000 g. Seed kernel is white, very oil and forms 63-83% of total weight while glumes forms 17-37% [8].

Castor-oil plant tends to continuous growth and remanent development that result in different periods of harvesting affects growth and development of castor-oil plant as an annual crop. Thus, forms of chinese subvariety have rapid development rates and weak vegetative growth, Zanzibar and Communis subvarieties are characterized by strong growth and slow development rates.

Castor-oil development has the following phases: emergence, formation of the central cluster, flowering, ripening of seeds of the central and lateral primary, secondary and other clusters [9].

Castor-oil plant reproduction is by seed. Seed germination goes by fat reserve consumption and at the expense of its energy plantlet develops. In dry seed corcule part is 3-3.5%, at the end of germination it is 87-88%; the mass of endosperm decreases from 97 to 12%.

The temperature minimum that support transition of seed from dormancy to vitality is physiological zero. Trials of Kherson Agricultural Institute proved that forms of Persydski castor-oil plant subvariety have the border of the lower physiological zero of 7.1-7.7 °C and forms of Sangvineus subvariety – 10.2°C, amount of effective temperatures for germination is 59.8°C, 53.6°C and 56.6°C respectively. Different speed of water uptake, chemical seed composition, ratio of hydrophilious colloids and hydrophobic fats results in different physiological zero and amount of temperature needed for subvarities germination [10].

Minimal (10°C), optimal (14-15°C) amd maximal (35-36°C) temperatures of castor-oil seeds germination are distinguished. Castor-oil seed has to absorb from 28 to 32% of water in order to germinate. Whereby, low oil content varieties absorb more water than seeds of high oil content varieties.

During the fruit-formation period seeds of the central clusters ripen, lateral brunches with clusters grow, fruits are formed on these branches, seeds are formed and ripened. Flowering and seed ripening of lateral primary and secondary clusters is an interphase. Ripening of seeds pods of the central clusters, which form 65-90% of total harvest of many varieties is an important development interphase.

In years with wet summer and warm autumn and under irrigation conditions the fruit formation period continues, whereas it reduces in drought.

Varieties grown in Ukraine need ammount of active temperatures (>10°C) from 2000 to 3800°C and no frost period for140-180 days [11].

The temperature conditions for castor-oil plant can not be examined separately from irrigation conditions. In these conditions moisture deficit is formed (especially in late sowing) and as a result castor-oil plant productivity dramatically decreases. In years with rainy and cool summer castor-oil plants has warmth deficit. High warm balance should be combined with adequate moisture regime.

3. Morphological and biological switchgrass characteristics

Switchgrass is a perennial crop. It can grow up to 3m 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. Diameter near stem base is 4-6 mm on average but forms with thin and thick stems are also present. Leaf blade is 50-60 cm long, width is 11-14 mm. 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 mass of 1000 seeds. The following ones: small mass group up to 1.5 g, average mass group up to 1.5-1.8 g and big mass group over 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.

Switchgrass plant (*Panicum virgatum L.*) consists of root system, stem, leaves, sheath, inflorescence in which in spikelets fruit (corn seed) is formed (figure 2).

Switchgrass goes the full development cycle (from seed to seed) throughout the first vegetation period. The crop completes intensive vegetation in October-November depending on genotype. The intensive plant regrowth begins after overwintering, in early spring. The phase of stem formation comes in the second decade of July. Flowering period lasts since the third decade of July till the first decade of August. Ripening period is late September – the middle of August. The vegetation period lasts 175-185 days [12].

Yield of above-ground plant phytomass in the period of panicle show is 42-64 t/ha, in the flowering period is 42.73-70.19 t/ha; dry mass is 10-15 t/ha; seeds is 500-600 (sometimes up to 1000) kg/ha. Plant energy productivity is 40 -60 (to 80) Gcal/ha [13].

Peculiarities of ontomorphogenesis of switchgrass plants have been examined during the first and the next life cycle. Depending on form and variety characteristics plants of early forms complete intensive vegetation

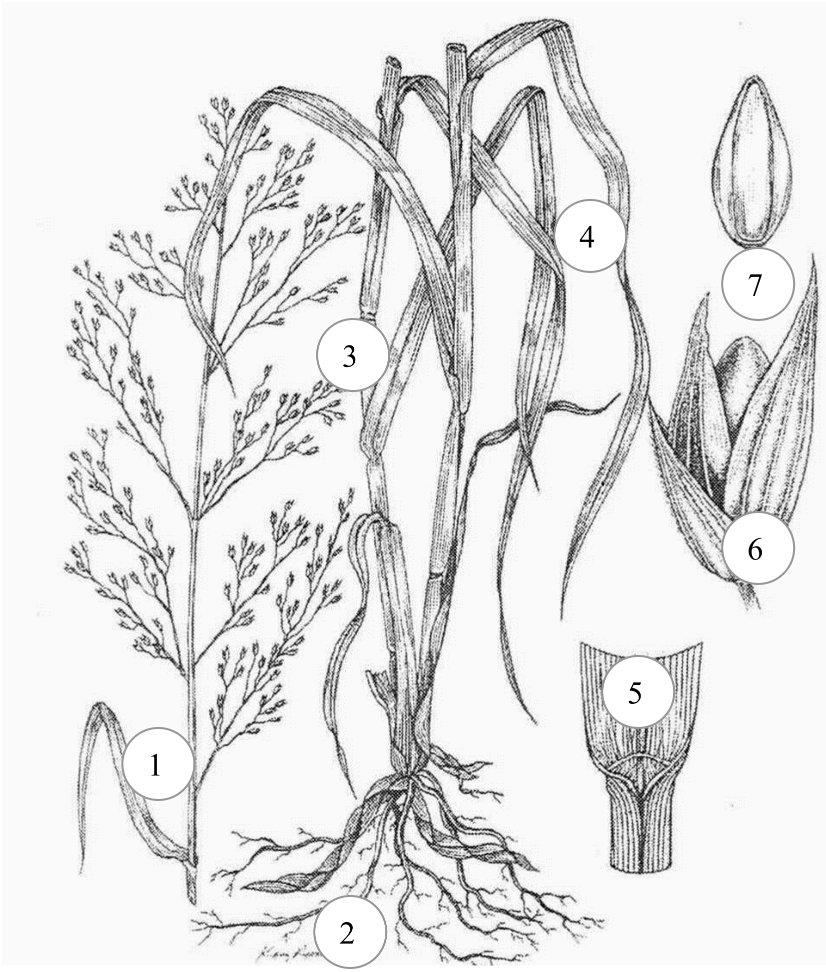


Fig. 2. Morphological structure of switchgrass plant (Panicum virgatum L.)

1 – inflorescence; 2 – root system; 3 – stem; 4 – leaves; 5 – sheath; 6 – spikelet; 7 – seeds.

in the third decade of August, the plants of middle forms complete vegetation till the end of September and the plants of late forms complete vegetation till the end of October.

In some years plants of late and very late forms have green colour till strong frost (–5…–7°C). Different autumn colouring of above-ground mass is typical for switchgrass plants of different forms and varieties and this testifies to plant vegetation completion.

In early June plant develops to the bushing out phase and formsplant density up to 50–70 cm.

Intensive plant growth lasts to the first decade of August when they develop to flowering phase and reach up to 140–160 cm.

Height parameters slow down till the beginning of seed ripening period. The seed ripening phase of different switchgrass forms comes in different terms and depends on the temperature regime.

During the vegetation period switchgrass goes through certain periods related to the changes of quantitative and qualitative plant characteristics. Therefore, we recommend to record the dates of the next development and growth phases after sowing, from emergence phase till the plant vegetation completion.

Planting-emergence period is rather long (to 30 days), that is linked to the structure of seed pellicle as well as demand of moisture for acceleration of biochemical changes in seed endosperm [14].

In the period of formation of the third true switchgrass leaf, secondary tillers separate from the stem node while the moisture is present for several days.

The next stages of growth and development are bushing out phase and stem formation phase.

The most intensive growth of switchgrass plants takes place in summer during flowering phase and gains nearly 75 % of total plant biomass. After flowering phase completion stems grow older and stiffen as fruit-bearing – seed ripening period comes.

In Ukraine growth and development cycle finishes in October-November till cold weather. During the period of vegetation completion reserve constituents pass from leaves and stems into bushing nodes and rhizome where they are stored till the next growth cycle. Renewal of spring vegetation is a start of the next stage of crop life cycle. Then phases of growth and development are repeated to the end of vegetation period. In Ukraine we have not observed senile period till 20 years. Thus, switchgrass can belong to cereal grass of very long, productive life cycle (more than 20 years) [15].

Investigation of switchgrass growth and development in the first and the next years will enable to study dynamics of quantitative and qualitative changes in ontogenesis, determine the duration of interphase periods during long life cycle. This will allow to define the most critical periods in organogenesis as well as work out optimization actions due to various fertilizers, biological components and land treatment.

4. Overview of the published works related to the research

Castor-oil plant is originated in Africa, it was grown in Egypt and gradually dispersed towards Asia, America and Europe.

The world sowing area of castor-oil plants is almost 1.5 million hectares. It is widespread in Brasil, India, Thailand and throughout other tropical countries. In Ukraine castor-oil plant sowing areas were 110-120 thousand hectares in the years of the USSR. This crop was mainly grown in Zaporizhia oblast, Mykolaiv oblast, Odessa oblast, Kherson oblast, Dnipropetrovsk oblast and Crimea [16].

Manifestation of castor-oil plant morphological characteristics depends on the environmental impact. Even slight changes of environmental factors such as humodity or temperature considerably affect vegetative organs [17].

Castor-oil plant is highly demanding to warm weather. Varieties grown in Ukraine need amount of active temperatures (>10 °C) from 2000 to 3800 °C and no frost period for 140-180 days.

In the emergence period, depending on the variety, essential amount of temperature is 160-350 °C, in the emergence-flowering period essential amount of temperature is 800-1200 °C and in the fruit-formation period is 1200-2000 °C. Varieties of different subforms have diverse warmth demands. In the field conditions emergence begin in 20-25 days at soil temperature of 10-12 °C, in 12-14 days at soil temperature of 14-16 °C and in 9-11 days at soil temperature of 18-20 °C [18].

Trials of V. N. Salatenka and V. K. Ivanova (1971) have shown that full-value uptake of warm weather potential of the south of Ukraine by castor-oil plants is possible only altogether with irrigation. It has been established that water consumption throughout the vegetation is 3000-5000 м^3 per 1 ha. It has been proved that castor-oil plants need no less than 180-200 mm of rainfall in order to provide average yield. Demands of humidity differ according to the periods. Humidity excess in the first part of vegetation and in autumn is harmful as it causes intensified growth of vegetative organs at the expense of reproductive organs. Castor-oil plants consume the greatest amount of water during the phases of flowering and seed filling. This period is critical. In Ukraine it lasts from late July till early August. In drought during this period leaves wither away, flowers and seed capsules fall off [19].

Conditions of optimal water availability are formed at moisture of active soil layer: in the period of flowering of the central raceme and the primary racemes no less than 80%, in the seed filling-ripening period no less than 65-70%. Excess of moisture in the third period results in unfavourable renewal of growth processes.

Moisture index of castor-oil plant changes depending on the cultivation conditions and varies from 300 to 630 and water consumption coefficient varies from 2600 to 3020 $м^3$ per 1 ton of seeds [20].

Switchgrass grows on eastern side of Rocky mountains at wide natural habitat, on the south along 55 degrees of northern longitude all the way down to Mexico and Central America. It is one of the main variety of north-american high grass which grows all over the prairies. The crop has been cultivated against soil erosion and natural preservation while also used for animal nutrition production. Switchgrass varieties are also populated on other continents where they are being cultivated for animal nutrition production [21; 22].

Switchgrass seeds are usually harvested in the second and the next years of vegetation. Switchgrass seed is relatively fine, mass of 1000 seeds varied from 1.76 g to 1.96 g. Average length of each seed is 2.4 mm, width is 1.0– 1.5 mm.

It has been established that a great part of harvested seeds does not germinate the next year after being harvested and can have only 10% of germination. However, prolong after-harvesting period of ripening, storage in warm and cool places, stratification increase this index. At this time grain ripening is stimulated and it resulted in malaxation of seed pellicle layers and acceleration of biochemical process in the corcule [23].

Adaptive responses of wild plants to unfavourable soil and weather conditions explain low emergence of switchgrass seeds. That is why considerable part of seed material is in biological dormancy [24].

Factors that cause a state of natural calm are very diverse – reduced activity of the embryo or various properties of seed membranes, etc. [25; 26]. Foreign scientists found that the resting state to the vast number of species is controlled by the hormonal system and the presence of certain acids in seeds [27].

High dormancy level can be reduced while storing seeds at low temperatures (4 °C) and relative humidity of 40% or at room temperatures for several years [28].

We determined that seed productivity can be 220–560 kg/ha and sometimes switchgrass provides up to 1000 kg/ha. In the conditions of forest-steppe of Ukraine switchgrass varieties Sunburst and Cave-in-Rock of the second vegetation year provide seed productivity of 597 and 373 kg/ha [29].

Switchgrass plants are able to take advantage of favourable conditions for growth and development and accumulate great amount of dry biomass during the vegetation period. However, proper requirements of cultivation conditions, especially to warm weather and humidity must be satisfied [29].

Impact of origin climate conditions resulted in switchgrass adaptability to high temperatures and sun intensity [30; 31].

5. Research methods

Multi-year researches have been conducted by field and laboratory trials. Study of seed productivity of castor-oil plant and switchgrass with quantitative characteristics depending upon weather of the vegetation period has been planned according to the programs of the research.

The area of seeding plot was 54.0 $м^2$, the area of accounting plot was 50 $м^2$, experiment repetition is four time. Plots were arranged in a randomized design.

The following observations and analyses have been used:

– planning and laying out of trials according to the methods of agronomy researches [32] and methods [33];

– phenological observations of plant growth and development have been made by the methods of state crop variety testing [34];

– quantitative characteristics of castor-oil plants have been determined by the methods [35], swithgrass characteristics by the methods [36, 37];

– seed yield has been accounted by weighing seed material of each plots followed by recalculation to 14% moisture [38];

– mass of 1000 seeds has been determined according to State Standards of Ukraine (DSTU) 4232-2003;

– statistical processing of the research results have been done by the analysis of variance (the least significant difference – LSD_{05}) as well as correlation and regression analysis, applying licensed computer programme Statistica–6.0.

6. Research results

Description of meteorological characteristics of the trial period (2012–2016 years) is highly important for establishing seed productivity level as castor-oil plant and switchgrass are quite sensitive to the weather changes during the vegetation period. Dynamics of daily average decade air temperature and precipitation during vegetation period (May-September) is shown in figure 3-4.

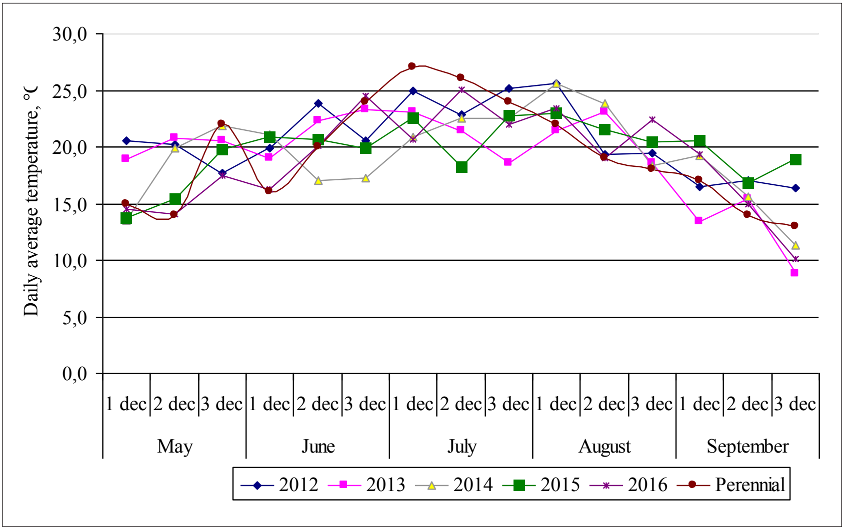


Fig. 3. Daily average and many-year average temperature during May-September period in 2012-2016 years

Daily average air temperature during May-September period shows increase of this characteristic in 2013-2014 and great decrease in 2012. Precipitation during this period of time was the highest in 2013 with decreasing to 18.9 mm in 2016. More reliable characteristic is hydrothermal coefficient (HTC), which varied from 0.1 (2012) to 1.2 (2015).

Having analyzed weather conditions of the vegetation period according to HTC index we have established that 2012 and 2013 year were dry,

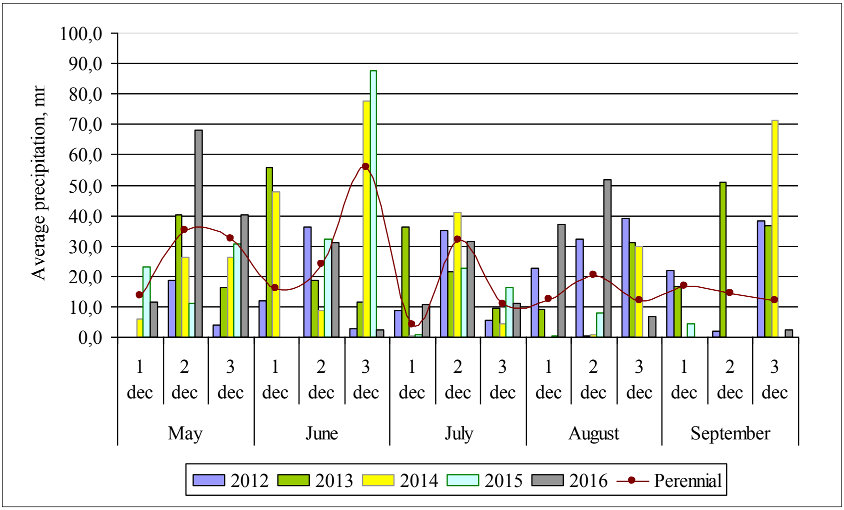


Fig. 4. Daily average and many-year average precipitation during May-September period in 2012-2016 years

2015 was subhumid, 2014 and 2016 years were characterized by average humidity.

Research results of castor-oil plant. Hydrothermal coefficient somehow affected quantitative castor-oil characteristics which by plant height, height of attachment of lower raceme, length and number of racemes, seed mass and size widely varied and depended on the conditions of the cultivation year (Table 1).

Table 1

Biometric characteristics of castor-oil plant, 2012-2016 years

Characteristics	**Vegetation year**					**Duncan test, p 0,05**
	2012	**2013**	**2014**	**2015**	**2016**	
Plant height, cm	68,8	175,9	173,5	179,1	187,0	9,2
The height of bottom raceme attachment, cm	40,1	78,8	57,3	78,5	116,6	9,3
Length of the central raceme, cm	13,9	25,4	22,9	36,8	32,6	4,8
Number of racemes	1,0	5,1	5,3	3,4	4,8	0,70
Mass of seeds per one plant, g	23,6	75,2	117,2	86,8	67,0	21,7
Mass of 1000 seeds, g	247,8	270,2	324,0	336,0	312,5	1,77

It has been determined that castor-oil plant height varied from 68.8 to 187.0 cm during the trial period. The highest plants were recorded in 2016. The weather conditions of this year were the most favourable for the last several years according to water availability and air temperature indices. In 2016 stable transition of daily average temperature from +10 °C to higher took place on April 5-6, 14-16 days earlier than usually. Precipitation in April-May exceeded 2-4 months means that resulted in faster crop vegetation. Summer months were quite warm and rainy. Lowering of daily average temperatures up to + 8-13 °C began in the middle of September. Such weather conditions were favourable for castor-oil seeds ripening.

The height of lower cluster attachment directly depends on water availability especially in the first part of the vegetation period. So, from 2012 to 2016 height of lower cluster attachment varied from 40.1 cm in 2012 to 116.6 cm in 2016.

The lenth of the lower cluster was the shortest in 2012 – 13.9 cm and the longest in 2015 – 36.8 cm. Castor-oil plant forms from 1 to 6-7 clusters depending on weather. Thus, in 2012 when precipitation was dramatically low during the vegetation period mostly only one cluster per plant was formed. In years with more water availability 3-6 clusters were formed. It has been established that the central cluster substantially exceeds the secondary and the third clusters by both size and number of seeds.

During the trial we recorded plants with 3-4 well-formed clusters or sometimes 5-6 clusters with small number of seeds. In early 2012 August castor-oil seeds were already ripened. However, rainfall in the second decade caused growth of the secondary branches and formation of additional inflorescences that negatively affected seed productivity.

The mass of seeds per one plant changed from 247.8 g in 2012 to 336.0 g in 2015. The wide range of this characteristic depended on both water availability of plants during the vegetation period and in which development phase rainfall and optimal temperatures were present. For example, in 2016 castor-oil plants were actively gaining vegetative mass because of excessive rainfall. But these conditions were not favourable for seed setting. Tthe mass of seeds per one plant was 67.0 g on average and the mass of 1000 seeds was 312.5 g.

Quantitative characteristics of castor-oil plants which highly affect castor-oil plant productivity have been determined by correlative-regression analysis (Table 2).

Table 2

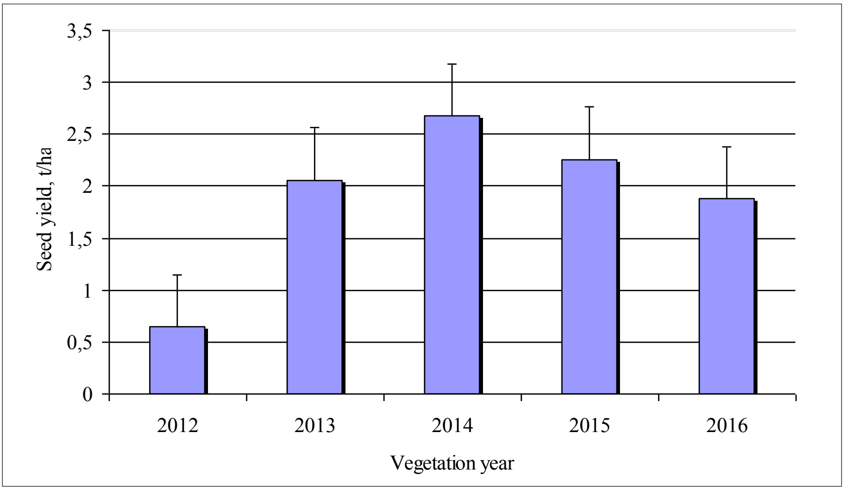
Correlation coefficient of quantitative plant characteristics and seed productivity of castor-oil plants, 2012-2016

Characteristics	Vegetation year				
	2012	**2013**	**2014**	**2015**	**2016**
Plant height, cm	0,53	- 0,11	0,42	0,43	0,22
Height of bottom cluster attachment, cm	0,40	- 0,05	0,34	- 0,02	0,33
Length of the central cluster, cm	0,80*	0,61*	0,37*	0,30*	0,69*
Number of clusters	-	0,82*	0,44*	- 0,17	0,79*
Mass of 1000 seeds, g	- 0,27	- 0,02	0,10	0,19	- 0,31

* Note: $p < 5{,}0\%$

The length of the central cluster and number of clusters per plant have the greatest impact on castor-oil plant productivity. In 2012 the length of the central cluster (r 0.80) had great impact on weight of seeds per plant. In 2015 this link lowered (r 0.30) and in 2014 number of clusters per plant had middle impact (r 0.44).

In 2013 and 2016 the length of the central cluster and total number of clusters affected castor-oil seeds productivity as well as seed yield of the crop (figure 5).



LSD 05 0,34

Fig. 5. Seed yield of castor-oil plants (t/ha), 2012-2016

It has been established that both quantitative characteristics of the generative part of plant and weight of seeds per area unit (r 0.87) had considerable impact on castor-oil plant yield. Weight of seeds per area unit depends on crop density and weather conditions of the organogenesis period. Crop yield was completely different as the weather conditions of the vegetation period during research years were variable. The lowest yield (0.65 t/ha) was recorded in the driest 2012. During next years crop yield increased and it was 2.22 t/ha for 4 years on average. The highest crop yield of 2.68 t/ha was provided in 2014 as this year had the most favourable temperature regime and precipitation in critical phases of the castor-oil plant development.

Thus, castor-oil plant is highly potential crop for cultivation in the central part of forest-steppe of Ukraine. Adequate rainfall and dynamics of annual average temperature increase enable to expand cultivation area of this strategic crop.

Research results of switchgrass. Quantitative characteristics of switchgrass plants changed in the wide range (Table 3).

Table 3

Biometric switchgrass characteristics, 2012-2016

Characteristics	Vegetation year					Duncan test, p 0,05
	2012	2013	2014	2015	2016	
Plant height, cm	138,3	141,5	178,0	182,0	174,1	3,2
Number of stems	198,7	213,5	309,6	303,5	310,6	6,5
Panicle length, cm	25,2	27,4	52,0	51,2	43,4	2,7
Panicle number	16,3	18,7	34,1	32,0	30,7	4,1
Mass of seeds per one plant, g	157,0	214,4	288,0	320,7	252,3	9,8
Mass of 1000 seeds, g	1,53	1,62	1,82	1,94	1,79	0,15

Throughout two years the height of plants varied from 138.3 to 182.0 cm. The highest plants grew in 2014 that was midhumid, lower plants grew in dry 2012-2013, and plants with middle height grew in insufficiently wet 2014 and 2016.

The highest number of switchgrass plants per area unit was in 2014 and 2016, less number was in 2012-2013 and average number was recorded in 2015.

The structural analysis of panicle revealed that total number of seeds from branches of different orders was 157.0-320.7 and depended on panicle length. Mass of 1000 seeds varied from 1.53 g to 1.94 g. The biggest mass of 1000 seeds was formed in 2014-2016 (HTC near or more than1.0), less mass was in dry 2012-2013 (HTC less than 1.0).

Connections between quantitative plant characteristics and seed productivity has been established by correlative-regression analysis (Table 4).

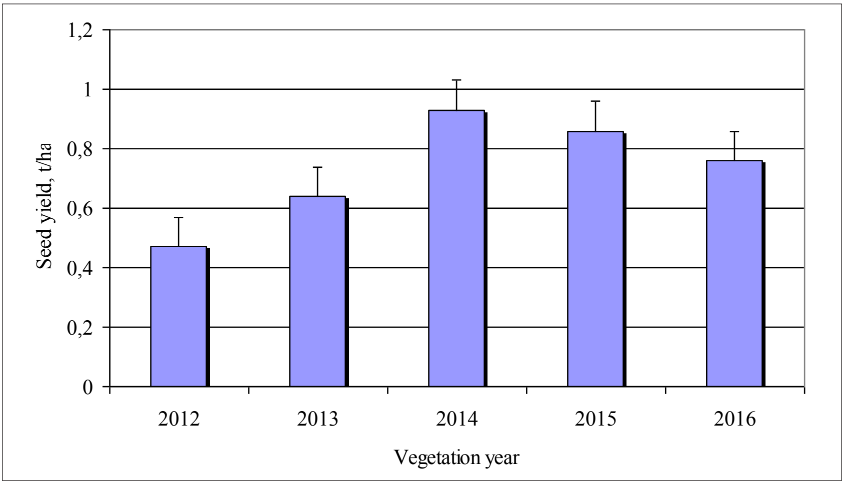
Table 4

Correlation coefficient of quantitative plant characteristics and seed productivity of switchgrass, 2012-2016

Characteristics	Vegetation year				
	2012	2013	2014	2015	2016
Plant height, cm	0,36	0,31	0,41	0,30	0,33
Number of stems	-0,12	- 0,04	-0,11	- 0,07	0,03
Panicle length, cm	0,73*	0,61*	0,78*	0,60*	0,65*
Number of panicles	0,25	0,32	0,41*	0,28	0,39*
Mass of 1000 seeds, g	0,31	0,20	0,14	0,17	0,11

* Note: $p < 5{,}0\%$

Panicle length and in some years panicle number per one plant have the strongest impact on switchgrass seed productivity. Switchgrass seed yield closely linked to productivity (r 0.80) was the highest in the years with HTC of moderate water availability (Figure 6).



LSD 05 0,13

Fig. 6. Yield of switchgrass seeds (t/ha), 2012-2016

The highest switchgrass yield was provided in 2014 and 2015 years (0.93 and 0.86 t/ha) LSD05 0.13, that is connected with morphological panicle characteristics and weather conditions during this period. Average yield was provided in 2016 (0.76 t/ha) and considerably less seed yield was in dry 2012-2013 (0.47 and 0.64 t/ha).

7. Conclusions

1. Biological peculiarities of castor-oil plant and switchgrass correspond with soil and climate conditions (temperature and water availability) in order to be cultivated in the forest-steppe of Ukraine.

2. High quantitative characteristics of castor-oil plant height, length of the central raceme and mass of 1000 seeds are formed in insufficiently wet years. Decreasing of these characteristics with simultaneous increase of raceme numbers and height of the central raceme attachment was recorded in dry conditions of the vegetation period.

3. It has been determined that length of the central cluster and sometimes number of racemes greater affect seed productivity of castor-oil plant during the vegetation period with adequate water availability, though in dry weather conditions length of the central cluster has the greatest influence and number of racemes does not exceed 1.

4. High biometric switchgrass characteristics (plant height, panicle length, number of panicles, mass and size of seeds) have been obtained in wetter years with HTC > 1.0.

5. High yield of switchgrass seed is provided under influence of length and number of panicles per plant in the conditions close to optimal. In dry weather conditions influence of panicle length increases whereas mass of 1000 seeds has average influence.

6. Yield of castor-oil seeds was the highest in 2014 (2.68 t/ha) with 2.03 t/ha lower in 2012, 0.65 t/ha lower in 2013, 0.42 t/ha lower in 2015 and 0.38 t/ha lower in 2016 by LSD05 0.34.

7. The highest switchgrass yield was provided in 2014 (0.93 t/ha), by LSD 05 – in 2015 (0,86 t/ha). This characteristic was 0.39 t/ha lower in 2012, 0.29 t/ha lower in 2013 and 0.17 t/ha lower in 2016.

Thus, taking into consideration research results according to biometric characteristics of plants and seed productivity depending on weather conditions, castor-oil plant can be recommended to be cultivated on farms in the forest-steppe of Ukraine in order to get technical oil of high quality and switchgrass is recommended to be cultivated for biofuel production and energy generation.

Prospects of the future researches will imply determination of impact of the cultivation technology elements on seed yield of lignocelluloses, sugar and oil crops considering weather and environmental factors.

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