Miscanthus giganteus in the Middle Volga region: opportunities and prospects

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Abstract. The main raw material for the production of cellulose is wood, which is also used as fuel, but it takes at least 80 years to regenerate forests. Therefore, it became necessary to find other possible sources of energy and cellulose. Miscanthus giganteus could become a possible and efficient renewable raw material. It also could replace forest crops in several ways. In this regard, in the Middle Volga region, which belongs to the zone of unstable moisture, the current research has been carried out since 2013 on the application of Miscanthus giganteus in light gray soil. Well-formed plants in the year the sowing with sufficient moisture provided the yield of the aboveground mass of 14 t/ha, in the second year it increased 2 times, in the third, despite the arid conditions, it reached 36 t/ha. The next two years were the most productive, when, with sufficient moisture, it was received 40 and 41 t/ha. In the severely arid years 2018 and 2019, it decreased by 9 and 11 t/ha, respectively, in relation to the fifth year of growing. The growing season of the last two years was favorable, but precipitation fell earlier or later than the critical phases of Miscanthus giganteus growing, which led to a decrease in yield to 25 t/ha. On average, per year, starting from the second year of growing, it could form 32 t/ha of energy biomass, which in terms of cellulose content, depending on the age of plants, is equal to wood (48.10-59.81%), and in terms of calorific value, raw materials correspond to the European standards.

1. Introduction

At present, the demand for fossil hydrocarbon raw materials is growing in the world. This problem dictates the need to find other possible energy sources. At the same time, the main requirement for them is environmental safety and economic availability [1-5]. These objects include, first of all, trees. However, their reproduction requires at least 80 years [6, 7]. Among herbaceous plants, the subject for consideration as a possible and efficient renewable raw material is Miscanthus giganteus growing, which could become an alternative to forest crops, since it is capable of producing 30-40 t/ha of dry matter. The high productivity of perennials is ensured by the efficient use of solar energy and water, since it belongs to plants with the C4 type of photosynthesis [8, 9]. Such a group of plants in the process of photosynthesis at a temperature of 30-45 ° C and intense illumination absorbs 40-80 mg/dm²·h of carbon dioxide, which allows them to more than two times reduce the consumption of water for the synthesis of a unit of production, in comparison with C3- photosynthesis. This advantage of Miscanthus giganteus increases its assimilation activity, and, consequently, biological productivity [10].

As a raw material source of non-wood origin, it could be grown by traditional agricultural methods on inefficient lands in terms of productivity. At the same time, Miscanthus giganteus would not compete with the main food crops for fertile soil [11]. However, agricultural producers still doubt
towards the application of such introduced species, since their growing could cause certain risks connected with low yields of the aboveground mass in the year of its planting, especially in the zone of unstable moisture, which includes the Middle Volga region. Under these conditions, Miscanthus giganteus would not always be able to realize its potential. Therefore, in areas where precipitation is the limiting factor, it is necessary to examine the benefits of Miscanthus giganteus growing, and determine its potential for productivity and quality of raw materials.

2. Materials and methods
The current research has been carried out on the application of Miscanthus giganteus in the forest-steppe zone of the Middle Volga region on the farming plot belonged to the university for nine years (2013-2021). The experiment was laid on May 6, 2013 on light gray soil with a low humus content - 2.7% (GOST (Russian State Standard) 23213-91) and easily hydrolyzed nitrogen - 102 mg/kg soil (according to the Kornfield method), high (188 mg/kg) - mobile phosphorus and medium (110 mg/kg) - exchangeable potassium (GOST 26204-21). In terms of acidity, the soil is close to neutral (GOST 26483-85).

The previous crop for Miscanthus giganteus was spring wheat, after harvesting which stubble was peeled by 10 cm and plowed to a depth of 22-25 cm with an interval of 7 days between operations, and in the spring of next year, harrowing was carried out to level the microrelief and close the soil moisture. When annual weeds reached the most vulnerable stage of the "white thread" of seedlings, the soil was cultivated and Miscanthus giganteus was planted to a depth of 8-10 cm by hand with a row spacing of 100 cm, in a row - 50 cm.

During visual inspection, the planting material was not damaged by diseases and pests, and 2-3 well-developed healthy buds were observed on each rhizome. Analysis of the results was carried out according to generally accepted methods [12, 13]. Energy assessment of seven-year-old Miscanthus giganteus stems was examined in an accredited laboratory of Incolab Services Russia S.C (St. Petersburg). The content of crude fiber was determined in the dry mass of plants according to GOST 31675-2012. The hydrothermal coefficient was calculated according to G.T. Selyaninov (1930).

3. Results and Discussion
When studying the scientific papers on the Miscanthus giganteus, it was found that it has a sufficiently high adaptive potential, capable of growing in one place for more than 20 years [14] with an annual precipitation of at least 700 mm [15] and on soils unsuitable for traditional agriculture [16].

In the Penza region, from the moment the experiment was laid in 2013 and until the harvesting of Miscanthus giganteus in the first ten days of May 2014, the amount of precipitation amounted to 664 mm, exceeding the average long-term by 164 mm, but 36 mm less than the crop needs. The sum of active temperatures (2643 °C) was 243 °C higher than the long-term one. More than half of the precipitation fell during its growing season, which lasted 133 days. Consequently, the Miscanthus giganteus growing proceeded under conditions of sufficient moisture with GTK-1.41 (Figure 1).

Under favorable environmental conditions, the raw material productivity of Miscanthus giganteus for the first year of growing was high (14 t/ha), since the distribution of precipitation by months was quite uniform, and their lack in May (GTC - 0.52) did not reduce germination, so the seedlings were fed due to the plastic substances of the maternal rhizome.

The overwintering of Miscanthus giganteus (2013-2014) was under difficult conditions, since there was a strong fluctuation in temperatures from + 1.2 °C to –31.7 °C and uneven precipitation in the form of snow and rain, followed by the formation of ice. The repetitive thaws and lower temperatures in March did not ruin the vegetative organs of renewal. Snow melting occurred gradually, but at the end of April the average daily temperature had already been established, exceeding + 10 °C, and the regrowth of Miscanthus giganteus was observed in the first ten days of May. Using the autumn-winter moisture reserves and May precipitation, the plants reached a meter height by June. In the summer months, there were elevated temperatures, the Hydrothermal coefficient (HK) was 0.7. Under such conditions, the process of photosynthesis intensified, but the consumption of moisture was
The plants reached a height of more than two meters. For the increase in the aboveground mass of precipitation in September and temperatures corresponding to the norm did not have a significant effect. 

![Graph showing the yield of Miscanthus giganteus depending on hydrothermal conditions.](image)

**Figure 1.** The yield of Miscanthus giganteus depending on the hydrothermal conditions of the cultivation zone.

By the time of harvesting, the plant height reached 2.2 m, the yield - 29 t/ha, that is, the crop yield in the second year of growing is due to the first year's growing. The melting of snow in the spring of 2015 was delayed; therefore, the regrowth of Miscanthus giganteus was observed 7 days later than in the previous year. The lack of moisture in May was compensated by its reserves in the soil. During the period of intensive growth of the aboveground mass (June, July), conditions of sufficient moisture developed, the plants reached a height of 3.85 m, the diameter of the stems at the base - 15 mm, which reduced the possibility of their lodging. The almost complete absence of precipitation in August and September (HK-0.15) did not affect the yield of green mass, which amounted to 36 t/ha, that is, in arid conditions (HK-0.62) of the growing season, the raw productivity of Miscanthus giganteus third growing year continues to increase. This is probably due to the amount of precipitation for the biological requirements of the crop, which fell in the sowing year.

The fourth and fifth growing years were under conditions of sufficient moisture at a HK of 1.27 and 1.32, respectively. But more optimal conditions for plants were formed in 2017, when during the growth phase of internodes, which occurred in June and July, HK was 1.15 and 1.41, relatively. However, it should be noted that for four-year-old plants (2016), the dry conditions of June (GTK-0.43) were not crucial, since Miscanthus giganteus used precipitation in May, the amount of which exceeded the norm by 2.2 times. Drought in August and excessive precipitation in September by 1.8-2.5 times did not change the structure of Miscanthus giganteus. The yield of the aboveground mass by the years of research was 40 and 41 t/ha.

The overwintering of plants in 2018 was at low negative temperatures and weak snow cover. Only in February and March, the amount of precipitation exceeded the average annual values by 25.1 and 17.3 mm, respectively. The temperature in April was 0.8 °C below the norm, therefore, due to the weak heating of the soil, Miscanthus giganteus grew late - at the end of May. The double norm of precipitation in the third decade of the month leveled their lack in June. The incipient growth of internodes continued in the next month, when the HK was 1.08, the average daily temperature...
exceeded the norm by 2.2 °C, the amount of precipitation was practically at the level of long-term values (70.1 mm). The existing conditions increased the photosynthetic activity of the leaves, but the plant height did not reach the level of the previous year and was only 2.7 m. Very dry (HK-0.25) and arid (HK-0.72) August and September conditions accelerated leaf drying, which led to a decrease in yield to 32 t/ha. With insufficient moisture in 2019, the productivity of Miscanthus giganteus remained at the level of the previous year - 30 t/ha, as the plants were affected by the effects of the drought of 2018 (HK-0.6) This is evidenced by the stalk per square meter (85 pcs. vs 132 pcs.) and height (2.24 m vs 2.70 m). On the eighth year of growing, taking into consideration the excess humidity in May (HK-3.22) and sufficient moisture in June (HK - 1.34), the vegetation period for Miscanthus giganteus was favorable (HK-1.24). However, from July to September, precipitation fell only 52% of the norm, and after a mild winter with a spring regrowth on May 20, the yield of Miscanthus giganteus was 5 t/ha less than in 2019.

The yield of the aboveground mass of 25 t/ha was also obtained in 2021. The increased April and May air temperature, and the weak thawing of the soil under the rhizomes did not stimulate the early resumption of growth buds on the old-growth plantation. Miscanthus giganteus began to grow only on May 24, so a strong increase in internodes began in mid-June. After determining the structure of the yield, it was found that with a plant height of 2.85 m, the stem was 196 pcs/m², the number of internodes, with an average length of 15 cm, did not exceed 12 pcs/plant.

The mass fraction of cellulose in Miscanthus giganteus stems, depending on the age of the plants, was in the range of 48.10-59.81%. Moreover, later harvesting gives higher yields. The calorific value of a 7-year-old sample was 17 MJ/kg or 4057 Kcal/kg, that is, with complete combustion of Miscanthus giganteus raw materials weighing 1 kg, more heat is released than according to the requirements of the European standard (at least 16.0 MJ). Consequently, the consumption of the obtained fuel raw material is reduced, since the specific heat of its combustion is higher.

4. Conclusion
Thus, studying the introduced species for nine years in the zone characterized by uneven precipitation not only by the years of research, but also during the growing season, it was found that with sufficient moisture in the year of planting Miscanthus giganteus, its raw material productivity could increase from 14 t/ha to 41 t/ha by the fifth year of rowing. Droughts, recurring in the next two years, led to a decrease in yield to 30 t/ha. With late spring regrowth of eight- and nine-year-old Miscanthus giganteus, May and July precipitation did not increase the intensity of plant development. Nevertheless, with a relatively low level of soil fertility, it had high productivity, and did not cause an invasive threat to agricultural lands, because in this zone it reproduces only vegetatively, and does not form seeds. On average, per year, with the second year of growing, it could form 32 t/ha of energy biomass, which in terms of cellulose content is equal to wood, and in terms of calorific value it exceeds the requirements of the European standard. In terms of economics and ecology, Miscanthus giganteus has significant advantages over alternative sources of fuel and cellulose.

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