Productivity of sweet potato \textit{(Ipomoea batatas \textit{L.})} in the conditions of the RF CRNZ

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Abstract. The results of sweet potato yield in the climatic and soil conditions of the Non-Chernozem zone are presented, which allow to recommend the expansion of the areas of valuable crops to ensure the industrial production of flour, starch, ethanol, and raw materials for semi-finished products. Due to its origin from a warm subtropical climate, it requires appropriate temperature conditions and humidity, especially in May, when there is a high risk of spring frosts. Therefore, an assessment of growing technology under cover for the total and commercial yield of tubers of six sweet potato varieties was carried out. In the conditions of the Non-Chernozem zone of Russia, the sweet potato samples Sukhumskiy (yield 21.7 t/ha), Amsterdamskiy (24.8 t/ha), and Jewel variety (23.4 t/ha) showed high productivity on average over 2 years. Under experimental conditions, a change in the growth rate was noted depending on changes in agro-climatic conditions, while periods of growth stoppage under unfavorable conditions (drought) and periods of continued growth, which subsequently caused deformation of tubers (especially in the Pobeda 100 sample) were noted. The rate of increase in the mass of tubers showed a positive correlation with the amount of precipitation.

1. Introduction

Sweet potato (Ipomoea batatas \textit{L.}) has an important nutritional and forage value in the world due to its nutritional value, root tubers and leaves contain carbohydrates, proteins, carotenoids, flavonoids, anthocyanins, phenolic acids, potassium, iron, calcium, vitamins \[1,2\]. More than 100 million tons of sweet potato are produced annually in the world, more than 60\% of world production falls on China \[3, 4\]. Sweet potato has a high potential for the industrial production of flour, starch, ethanol, and as a raw material for the production of semi-finished products: dehydrated chips, cereals, jams, jellies, flour, and pasta \[5,6\]. Intake of sweet potato can have antioxidant, cardioprotective, anti-inflammatory, anti-cancer, antidiabetic, antimicrobial effects. Useful parts of sweet potato are leaves and underground tubers weighing up to 3 kilograms, growing from lateral roots \[7, 8\]. Sweet potato leaves and tubers are characterized by high nutritional value, in particular high content of antioxidants, vitamins, and minerals. Varieties with orange pulp are a source of β-carotene, while varieties with purple pulp have a high level of anthocyanins \[11,12\]. Sweet potato is not demanding of soil fertility, has the ability to adapt to a wide range of climatic conditions, primarily to drought \[13\]. Reproduction is carried out by adventitious roots, stem or root cuttings. Among forage crops, sweet potato has a greater ability to accumulate dry matter over a long period of time. In recent years, interest in sweet potato in the world has increased due to the diverse use of tubers in the nutrition of humans and animals, as well as their use in the food, pharmaceutical industry, in the production of probiotic food
Over the past five years, the import of sweet potato to Russia has increased 12 times, reaching 2.3 thousand tons in 2020, an increase of 1.2 times compared to the level of 2019. At the same time, the price of sweet potato ($5.0-6.5 per kg) in the retail network significantly exceeds potato. The main supplier of sweet potato to Russia is Egypt, as well as Honduras, Israel, Guatemala, China, and Vietnam. Due to the increasing demand for sweet potato, studies on the assessment of sweet potato productivity, the development of methods for managing the crop production process in the Non-Chernozem zone are of great industrial importance, primarily for the import substitution strategy [16, 17].

2. Methods and materials

The assessment of food sweet potato samples in the conditions of the RSAU-MAA field experimental station was carried out for the first time. Since there are currently no registered varieties and scientific collections in the Russian Federation, not only varieties (Jewel) were used in the research, but also sweet potato samples obtained from private collectors of the Leningrad region, which status has not been established. The productivity of sweet potato samples was evaluated on sod-podzolic soils of a field experimental station belonging to the RSAU-MAA named after K.A. Timiryazev [55°50'29.73" N, 37°33'38.93" E] (city of Moscow). The variants were placed by the randomization method, in three-fold repetition. Pre-sprouted cuttings of sweet potato samples were used for planting: Amsterdamskiy, Sukhumskiy, Tainung, Pobeda 100 (Russia), Jewel (USA), Portu Batteraba (Portugal) (Table 1).

| Sample/Accession | Peel color | Pulp color                  | Physiological age (months) |
|------------------|------------|-----------------------------|----------------------------|
| Amsterdamskiy    | pink       | cream                       | 3.5                        |
| Sukhumskiy       | pink       | cream                       | 3.5                        |
| Tainung          | pink       | cream                       | 3.5                        |
| Pobeda 100       | pink       | cream with pink inclusions  | 3.5                        |
| Jewel            | copper     | orange                      | 3.5                        |
| Portu Batteraba  | dark pink  | light yellow                | 3.5                        |

Planting was carried out in the 3rd decade of May, in ridges insulated with covering material. Planting scheme: 110x40. Fertilizers and pesticides were not used during the growing season.

Phenological observations were carried out in phases: the initial phase of intensive root growth (moderate growth rate); the middle phase (intensive growth of shoots, tuber formation), the final phase (increase in tuber mass). The following indicators were determined: the length and number of shoots, the chlorophyll content in sweet potato leaves (the atLEAF Chl device); indicators of the crop structure: the amount and mass of tubers, the largest diameter, the shape index. Gathering was performed manually, in the first decade of October, gathering was carried out at the age of physiological maturity (BBCH 97 stage). At the experimental site, all records, observations, measurements, and analyses were carried out according to generally accepted methods and agricultural recommendations.

2.1. Weather, Meteorological Data

The amount of precipitation and average temperature were collected and analyzed for 2020-2021 at the study site from April to October during the growing season of sweet potato plants. The distance between the experimental field and the university weather station was 0.64 km. The years of research differed markedly in terms of heat and moisture availability from the average long-term data (Table 2).
Table 2. Meteorological conditions during sweet potato growing season (Data from the Observatory named after V.A. Mikhelson, Moscow).

| Meteorological data             | 2020 | 2021 |
|---------------------------------|------|------|
| Sum of temperatures ≥ 10°C, °C | 2344 | 2215 |
| Average temperature, °C         | 17.8 | 16.4 |
| Precipitation, mm               | 526  | 624  |

Sweet potato, due to its origin from a warm subtropical climate, requires appropriate temperature conditions and humidity, especially in May, when there is a high risk of spring frosts, therefore, the purpose of the research was to assess the productivity of sweet potato with a ridged growing method, using covering materials. Tainung sweet potato samples, Pobeda 100, Portu Batteraba were susceptible to arid conditions – high temperatures and drought led to premature leaf death, which subsequently affected yields. The soil of the experimental site was characterized by a slightly acidic reaction (6.5 pH in KCl), a humus content of 2.0%, a high phosphorus content (225 mg/kg), an average potassium content (110 mg/kg of soil dry matter).

2.2. Statistical analysis

The obtained results were subjected to statistical analysis. An ANOVA test was analyzed, while the significance of the differences between the mean values was determined using Tikeu's criterion (LSDα=0.05). Statistical analysis was carried out using the Statistica 10.0 software.

3. Results and Discussion

Sweet potato plants have a lodging stem, varieties can be classified as erect bushy, intermediate or spreading, depending on the length of their shoots. Branching depends on the variety, sweet potato shoots vary in amount and length. Sweet potato plants are characterized by three types of branches: primary, secondary, and tertiary, which are formed during different growth periods. The total number of branches in the experimental conditions varied from 4 to 10 in different samples, while the stem length varies from 0.5 to 1 m, the nature of branching in sweet potato plants depended on the photoperiod and soil moisture (Table 3).

Table 3. Length (m) and number of stems (pieces/plant) of sweet potato.

| Sample/Accession    | Length of shoots, m | Number of stems, pieces/plant |
|---------------------|---------------------|-------------------------------|
| Amsterdamskiy       | 0.73                | 7.80                          |
| Sukhumskiy          | 0.95                | 7.10                          |
| Tainung             | 0.94                | 10.3                          |
| Pobeda 100          | 0.72                | 4.60                          |
| Jewel               | 0.96                | 9.12                          |
| Portu Batteraba     | 0.46                | 4.24                          |
| LSDα=0.05           | 0.04                | 0.39                          |

The increase in stem length and the total number of shoots on the plant in the Tainung variety was due to the formation of secondary shoots. The studied sweet potato samples had lodging stems, with horizontally unfolded leaves, allowing effective use of solar insolation. As new leaves grew during the growing season, the old leaves died off. The number of leaves depended on the number of shoots, the length of stems and internodes, the speed and duration of leaf formation, as well as the lifespan of the leaves. The total number of leaves on the plant in different samples varied between 42-114 pieces per plant. Sweet potato photosynthesis is typical for C3 plants. The chlorophyll (chl) concentration in the
leaves was determined by variety characteristics (Table 4). The chlorophyll (SPAD) content in the leaves remains relatively constant throughout the entire growth period, decreasing by an average of 0.3-0.6 units by the harvest period.

Table 4. Chlorophyll content in sweet potato leaves (average for 2 years).

| Sample/Accession    | Phase of 3-4 leaves | Phase of 6-7 leaves | Phase of vegetative growth | Before gathering |
|---------------------|---------------------|---------------------|----------------------------|-----------------|
|                     | SPAD, units | Total chl, mg/cm² | SPAD, units | Total chl, mg/cm² | SPAD, units | Total chl, mg/cm² | SPAD, units | Total chl, mg/cm² |
| Amsterdamskiy       | 48.38      | 0.05                | 46.65       | 0.05                | 47.60       | 0.05                | 40.70       | 0.04                |
| Sukhumskiy          | 47.22      | 0.05                | 47.87       | 0.05                | 48.33       | 0.05                | 41.73       | 0.04                |
| Tainung             | 41.10      | 0.04                | 39.47       | 0.04                | 40.58       | 0.04                | 34.08       | 0.03                |
| Pobeda 100          | 45.02      | 0.05                | 43.98       | 0.04                | 43.92       | 0.04                | 39.58       | 0.04                |
| Jewel               | 48.20      | 0.05                | 46.34       | 0.05                | 47.44       | 0.05                | 41.30       | 0.04                |
| Portu Batteraba     | 43.93      | 0.04                | 46.38       | 0.05                | 43.60       | 0.04                | 39.08       | 0.04                |

The assessment of the photosynthetic apparatus's resistance to the extreme effects of vegetation on the basis of chlorophyll fluorescence in leaves allowed to establish the following pattern: with a SPAD of less than 40 units, there was a change in the shape index in samples Pobeda 100 (1.2), Portu Batteraba (1.1), with a general decrease in tuber weight and yield. The genetic characteristics of the samples and meteorological conditions during the years of research significantly affected the structure of the tuber yield. The most favorable structure of the tuber mass in the total yield was obtained in 2021, large tubers with a mass of 0.61 kg (64%) prevailed in the crop structure, 2020 was characterized by drought in the last three months of sweet potato cultivation, which provoked an increase in the share of the total yield of tubers of the fraction <0.20 and 0.21-0.40 kg in Sukhumskiy, Tainung, Pobeda 100, Portu Batteraba samples (Table 5).

Table 5. Structure of sweet potato yield.

| Sample/Accession    | Number of tubers, pieces/plant | Tuber weight, g | Shape Index | Weight of tubers, g/plant | Yield t/ha |
|---------------------|--------------------------------|-----------------|-------------|---------------------------|-----------|
| Amsterdamskiy       | 3.8                            | 406.5           | 0.9         | 1090.6                    | 24.8      |
| Sukhumskiy          | 6.5                            | 165.6           | 1.4         | 953.70                    | 21.7      |
| Tainung             | 6.2                            | 127.4           | 1.4         | 773.00                    | 17.6      |
| Pobeda 100          | 5.4                            | 101.4           | 1.2         | 547.60                    | 12.4      |
| Jewel               | 4.6                            | 243.3           | 1.3         | 1027.4                    | 23.4      |
| Portu Batteraba     | 5.5                            | 53.20           | 1.1         | 345.90                    | 7.90      |
| LSDα=0.05           | 0.29                           | 10.06           | 0.07        | 43.43                     | 0.99      |

The sweet potato samples Sukhumskiy (yield 21.7 t/ha), Jewel (23.4 t/ha) and Amsterdamskiy variety (24.8 t/ha) were the most productive on average for 2 years in the conditions of the Non-Chernozem zone of Russia. The sweet potato yield was determined by the duration and growth rate of tubers, which differed significantly. Under experimental conditions, a change in the growth rate was noted depending on changes in agro-climatic conditions, while periods of growth stop under unfavorable conditions (drought) and periods of continued growth were noted, which subsequently
caused deformation of tubers (especially in the Pobeda 100 sample). The rate of increase in the mass of tubers showed a positive correlation with the amount of precipitation.

4. Conclusion
To form a high yield for sweet potato crop during the growth period (120-125 days) at least 500 mm of precipitation is required, but the timing and distribution of water over the growing season have a significant impact on productivity. There was a decrease in yield under stress from water scarcity, in the dry 2020, especially when the available soil moisture decreased below 18%. The decrease in tuber yield is also associated with physiological and biochemical changes in the leaves - with SPAD of less than 40 units, there was a change in the shape index in samples Pobeda 100 (1,2), Portu Batteraba (1,1), with a general decrease in tuber weight and yield. Under conditions of water stress, the water potential of the leaves decreases, which leads to premature aging and leaf death. Despite the high demands of the crop for heat, in the conditions of the Moscow region, sweet potato plants are able to develop successfully, form a developed aboveground part with a strong assimilation apparatus. Among the studied samples, both with high shoot-forming ability (Tainung, Jewel) and with a compact aboveground part, with high technological efficiency in growing for the production of tubers (Pobeda 100, Portu Batteraba) were identified. The studied samples had different adaptive capacity to water stress: the total chlorophyll content in sweet potato leaves decreased, especially significantly in the samples of Tainung (by 4.7 units), Pobeda 100, and Portu Batteraba (by 1.3... 1.6 units), which subsequently affected the yield of tubers. In conditions of excessive moisture, an intensive increase in the aboveground mass was noted, which led to a low production of tubers.

The agro-climatic conditions of the Non-Chernozem zone of Russia allow cultivating sweet potato to obtain commercial tubers. Sweet potato samples are recommended for cultivation: Amsterdamskiy, Sukhumskiy, Jewel.

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References
[1] Reddy R et al 2018 Morphological characterization of sweet potato cultivars during growth, development and harvesting Indian Journal of Agricultural Research 52(1) 46-50
[2] Zhang H et al 2020 Root yield, antioxidant capacities, and hormone contents in different drought-tolerant sweet potato cultivars treated with ABA under early drought stress Acta Physiologiae Plantarum 42(8) 1-15
[3] Huang F et al. 2020 Differences in absorption of cadmium and lead among fourteen sweet potato cultivars and health risk assessment Ecotoxicology and Environmental Safety 203 111012
[4] Beam S et al 2018 Response of sweetpotato cultivars to linuron rate and application time Weed Technology 32(6) 665-670
[5] Xiangbei D et al. 2019 Split application improving sweetpotato yield by enhancing photosynthetic and sink capacity under reduced nitrogen condition Field Crops Research 238 56-63
[6] Smith S et al. 2022 Evaluation of Sweetpotato Cultivars with Varying Canopy Architectures in Conventional and a Reduced-tillage Rye Production System HortTechnology 32(2) 158-163
[7] Park S et al 2020 Selection of flooding stress tolerant sweetpotato cultivars based on biochemical and phenotypic characterization Plant Physiology and Biochemistry 155 243-251
[8] Indawan E et al. 2018 Sweet potato response to biochar application on sub-optimal dry land. Journal of Degraded and Mining Lands Management 5(2) 1133
[9] Dladla L et al. 2018 Yield, water use, and water use efficiency of sweet potato under different environments. In *XXX International Horticultural Congress IHC2018: International Symposium on Water and Nutrient Relations and Management of 1253* 287-294

[10] Hayati M et al. 2020 Morphological characteristics and yields of several sweet potato (Ipomoea batatas L.) tubers. In *IOP Conference Series: Earth and Environmental Science* 425 012055

[11] Huan L et al. 2020 Photosynthesis product allocation and yield in sweet potato with spraying exogenous hormones under drought stress. *Journal of Plant Physiology* 253 153265

[12] Wijewardana C et al. 2018 Low and high-temperature effects on sweet potato storage root initiation and early transplant establishment. *Scientia Horticulturae* 240 38-48

[13] Melo R et al. 2020 Evaluation of purple-fleshed sweetpotato genotypes for root yield, quality and pest resistance *Horticultura Brasileira* 38 439-444

[14] Delazari F et al. 2018 Morpho-physiological characteristics by sweet potato cultivars as function of irrigation depth *Anais da Academia Brasileira de Ciências* 90 3541-3549

[15] Gurmu F et al. 2018 Correlation and path-coefficient analyses of root yield and related traits among selected sweetpotato genotypes *South African Journal of Plant and Soil* 35(3) 179-186

[16] Povarnicyna A et al. 2021 Vozmozhnosti vyrashchivaniya batata v agroekologicheskikh usloviyah Central'nogo rajona nechernozemnoj zony 73-8 151-155

[17] Magomedova B et al. 2017 Batat kak cennaya pishchevaya kul'tura dlya respubliki Dagestan (Pervoe soobshchenie) //*Botanicheskij vestnik Severnogo Kavkaza* 4 24-33