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The Influence of Abiotic Factors on the Growth and Development of Parsnip Plants

Abstract. The main drivers influencing plant growth, yield increase and its quality characteristics are biotic and abiotic factors. Combinations of abiotic stresses, such as drought and heat, have a much greater impact on yields and product quality. Plants' response to these stresses can vary depending on the species and different stages of development. Understanding the mechanisms and how they protect plants from stress has become vital for improving the yield and quality of parsnip products in changing climates. The purpose of the study was to determine the influence of abiotic factors (temperature and precipitation) on the yield, duration of phenological phases of growth and development of plants, the dynamics of leaf and root mass growth of parsnip in the conditions of the Right-Bank Forest-Steppe of Ukraine. The research was carried out in the field experiment of the Department of Vegetable Growing and Closed Ground in the National Research Institute "Fruit and Vegetable Garden" of NUBiP of Ukraine within the conditions of the Right-Bank Forest-Steppe of Ukraine during 2015-2017. The area of the registered plot was 11.3 m^2, and the repetition rate of the experiment is four times. The placement of variants is systematic. The research found that the shortest sowing-emergence period lasted 16 days in the variants sown in the 3rd ten-day period of May and the 1st ten-day period of June. A significant delay of 21 days in this period was noted for sowings from 1st to 3rd ten-day periods of April. The duration of the period from the beginning of root crop formation to bunch ripeness was the shortest when sown in the 1st ten-day period of April – 28 days, and the longest when sown in the 1st ten-day period of June – 51 days. The growing season ranged from 110 to 165 days and was characterised by GDD (>10°C) of 1102.4-1439.0°C and precipitation of 128.1-225.2 mm. After sowing in April, intensive growth of root crops from 2.9 to 3.5 g / day was observed in the second half

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of August. After sowing in May, the greatest increase in root crops from 2.1 to 2.7 g/day was noted in the first half of September. Thus, for sowings in the 1st ten-day period of June, this figure was the highest in the second half of September (1.9 g/day). The variant sown in the 1st ten-day period of April provided a high yield of root crops of 50.3 t/ha, which is 5.3 t/ha or 11.8% significantly more than the control variant. When sowing in the following terms, a significant decrease in yields was observed compared to the control, namely: for 3rd ten-day period of April – by 3.5 t/ha, or 7.7%, for 1st ten-day period of May – by 8.8 t/ha, or 19.6%, for 2nd ten-day periods of May – by 17.4 t/ha, or 38.6%, for 3rd ten-day periods of May – by 23.0 t/ha, or 51.1%, for 1st ten-day period of June – by 31.7 t/ha, 70.6% compared to the control. A strong direct correlation ($r = 0.74$-0.99) was found between the growing season and yield, root mass, marketability, and biochemical parameters, namely: dry matter, dry soluble matter, sugars, vitamin C. An inverse correlation ($r = -0.98$) was observed between the duration of the growing season and nitrates. Increasing the growing season by 10 days increases the yield up to 6.9 t/ha, marketability up to 2.7%, root weight up to 31 g, dry matter content up to 0.7%, dry soluble matter up to 0.3%, sugars up to 0.5%, vitamin C up to 0.8 mg/100 g and reduces the nitrate content to 8.4 mg/kg. Leaf area, photosynthetic potential, and net photosynthetic productivity are strongly directly related ($r = 0.92$-0.98) to yield. For increasing the leaf surface area to 1.0 thousand m^2 the yield is also growing up to 0.7 t/ha. Increasing the photosynthetic potential to 0.05 million m^2 days/ha increases the yield to 0.2-1.2 t/ha. Also, the yield increases to 0.3-0.7 t/ha with an increase in net photosynthetic productivity to 0.05 g/m^2 per day. The molecular knowledge on plant responses to abiotic stress is promising for further study and is likely to advance crop resilience to climate change and increase the economic efficiency of production.

Keywords: parsnip, temperature, precipitation, yield, growth of roots and leaves

RELEVANCE

One of the consequences of global climate change has been a steady decline in the availability and productivity of arable land (Zandalinas *et al.*, 2018). The main factors that have a major impact on plant growth, yield increase and its quality characteristics are biotic and abiotic factors that influence or even determine the final result (Atkinson & Urwin, 2012).

Abiotic factors such as extreme temperatures, droughts, floods, salinity, and heavy metals are among the main factors limiting productivity and crop quality (Kumar, 2020). Combinations of abiotic stresses are known to affect the appearance and spread of biotic stresses such as insect pests, pathogens, weeds, etc. (Ziska *et al.*, 2010; Peters, 2014). Reduced plant growth due to drought or heat is a frequent and widespread phenomenon all over the world. In the case of a combination of both stresses, their effect on crop yields is more severe than that of a particular stress (Sehgal *et al.*, 2017).

The expected temperature changes for the next 30-50 years are assumed to be in the range of 2-3°C. Heat waves or temperature extremes will become more intense, more frequent and last longer than what has been observed in recent years (Hatfield & Prueger, 2015). Extreme temperature periods can have a short duration of a few days with temperature increases of more than 5°C above normal temperatures (Kumudini *et al.*, 2014).

ANALYSIS OF RECENT RESEARCH AND PUBLICATIONS

The temperature response is different for different crop species throughout their life cycle

(Hatfield *et al.*, 2011; Komar *et al.*, 2021). One of the most vulnerable phenological stages to high temperatures is the pollination stage (Shengbao *et al.*, 2020; Bobos, 2019).

Drought stress is associated with a lack of water for the plant, which significantly affects growth, development and yield. There are two types of drought: physical drought (lack of water due to unavailability) and physiological drought (inability of a plant to absorb water from the soil due to various physiological reasons such as salinity, freezing, etc.) (Vadez *et al.*, 2012).

Low temperature (cold stress) also affects the biochemical and physiological activity of plants and, consequently, the yield and quality of products. Low temperature disrupts the membrane structure, protoplasmic flow and causes electrolyte leakage/plasmolysis. Temperature affects mineral absorption, photosynthesis, respiration, and metabolism. Plant response to low-temperature stress is associated with changes in gene transcription associated with the production of several low molecular weight proteins (Yadav *et al.*, 2017).

Water stress includes its deficiency or excessive presence in the environment. Excess water or flooding affects the availability of oxygen to plants, causing low oxygen levels/hypoxia (Sasidharan *et al.*, 2017). Five ERF (ethylene response factor) genes are key regulators of flood resistance and hypoxia tolerance. Studies demonstrate the presence of physiological, genetic, epigenetic and molecular mechanisms in plant resistance to flooding (Gasch *et al.*, 2016).

Parsnips are native to Mediterranean countries (Colombo *et al.*, 2011). Parsnip is a biennial, cold-hardy crop common in many European and Asian countries (Zohary *et al.*, 2012). The origin of plants determines their relation to the environment. Parsnip plants can tolerate frost, although severe cold during the growing season will lead to their death. Parsnip root crops winter well provided there is sufficient snow cover. In spring, the overwintered rosette resumes growth and stem, inflorescence and seeds are formed (Cain *et al.*, 2010).

All parts of the plant contain aromatic essential oils, but the greatest amount of them is found in seeds from 1.5 to 3.6%. Therefore, seeds are characterised by a weak wettable surface, low water retention capacity of the seed coat and increased absorption capacity (Berenbaum & Zangerl, 2006;. Zangerl *et al.*, 2008).

The efficiency of germination is determined by the size and weight of the seeds. Larger and heavier parsnip seeds have high germination energy and produce friendly seedlings, which contributes to high yields. Seed germination is most strongly correlated with seed weight, as filled seeds contain more nutrients for germination (Shankar, 2006; Norden *et al.*, 2009; Kaliniewicz, *et al.*, 2014). The efficiency of seed germination can be improved by mechanical, chemical, physical, and biological methods (Ciupak *et al.*, 2007; Lynikiene *et al.* 2006).

Therefore, understanding the mechanisms and how they protect plants from stress has become vital for improving the yield and quality of parsnip products in changing climates.

The purpose of the study was to determine the influence of abiotic factors (temperature and precipitation) on the yield, duration of phenological phases of growth and development of plants, the dynamics of leaf and root mass growth of parsnip in the conditions of the Right-Bank Forest-Steppe of Ukraine.

MATERIALS AND METHODS

Field studies were conducted in 2015-2017 on the experimental field of the Department of Vegetable Growing and Indoor Ground in the National Forest “Fruit and Vegetable Garden” of NUBiP of Ukraine in the conditions of the Right-Bank Forest-Steppe of Ukraine. The soil of the experimental plot is soddy-medium podzolized, coarse silt, light loamy.

The following terms of sowing parsnips were studied: 1st ten-day period of April, 2nd ten-day period of April (control), 3rd ten-day period of April, 1st ten-day period of May, 2nd ten-day period of May, 3rd ten-day period of May, 1st ten-day period of June. The size of the experimental plot was 11.3 m², the repetition is fourfold. Variants in the experiment were placed systematically. The predecessor for parsnips was cucumber. The studies used the Stimul variety. Sowing was carried out according to the scheme 45x10 cm to a depth of 1.5-2 cm.

The tasks of phenological observations included recording the date of sowing, the emergence of seedlings, the formation of 1-3 true leaves, the beginning of root crop formation, the beginning of bunch ripeness, technical ripeness. The beginning of the phase was recorded when 10% of plants on the plot showed relevant signs, with 75% of plants showing it in mass (Bondarenka & Yakovenka, 2001).

Biometric observations included determining plant height, counting leaf count, leaf and root mass, leaf area, photosynthetic potential, and net photosynthetic productivity.

The dynamics of leaf area were determined by contour scanning of leaves with a further determination of their area using IpSquare 1.9 software. Leaf area per 1 ha of the crop was calculated based on plant density and expressed in thousand m² per 1 ha.

To determine the photosynthetic potential of seeding, the assimilation surface of typical plants was regularly measured. Then the leaf area per 1 ha of the crop was calculated by multiplying the average assimilation surface of one plant by the number of plants per 1 ha. The obtained data were placed on graph paper with a time scale on the horizontal axis (abscissa) corresponding to 5 days in 1 cm, leaf area (ordinate axis) – 4000 m² in 1 cm. According to this scaling markings showing the results of leaf area determinations were drawn on a millimetre sheet. Connecting the points, a curve was drawn, which showed the progress of leaf area growth per 1 ha during the growing season. Then, the area of the figure (cm²) bounded by the abscissa axis, derived by a curve and a perpendicular lowered from the end point of the curve to this axis was determined. The photosynthetic potential was determined by the formula:

$$PH_p = S \times O \times A; \qquad (1),$$

where PH_p – photosynthetic potential, mln m² x days/ha; S – the area of the figure, cm²; O – the price of one centimetre on the scale along the ordinate axis (4000 m²); A – number of days.

Net productivity of photosynthesis (NP) was determined by the amount of dry mass growth per day per 1 m² of leaf surface according to the formula of Kidd, West and Briggs:

$$PH_{\text{n.pr.}} = \frac{B_1 - B_2}{{}^1/_2 \times (L_1 + L_2) \times n}; \qquad (2),$$

where $PH_{\text{n.pr.}}$ – net photosynthetic productivity, g/m² × day; B_1 and B_2 – dry weight of the sample, at the beginning and end of the accounting period, g; (B_1 - B_2) – dry weight gain for the accounting period; L_1 and L_2 – area of the sample leaves at the beginning and end of the period, cm²; ½ × (L_1 + L_2) – average area of leaves “working” during the accounting period; n – the number of days in the accounting time interval, days.

GDD > 10°C and precipitation were estimated for the general characterization of heat accumulation and humidification of the territory during the growing season of plants and each of their interphase periods.

Root crops were harvested in each replication by continuous method. They were sorted according to the requirements of DSTU 8473:2015 “Fresh parsnips. Technical conditions”. The average weight of marketable roots was determined by the average sample of 5 kg. The number of root vegetables was calculated and the average weight of marketable root vegetables was determined.

Biochemical studies were carried out in the Ukrainian Laboratory of Product Quality and Safety of the Agro-Industrial Complex of the National University of Bioresources and Nature Management of Ukraine according to standardised methods: the content of dry matter was determined by the thermogravimetric method (DSTU ISO 751:2004), the content of soluble dry matter was determined by the refractometric method (DSTU 8402:2015), total sugar content by Bertrand's method (DSTU 4954:2008), ascorbic acid (vitamin C) by the Murray method (DSTU 7803:2015), and the number of nitrates by ionometric method (DSTU ISO 4948:2008). Statistical processing of the obtained research results was performed by the method of variance and correlation-regression analysis (Kwanchai & Arturo, 1984; Rao, 2007).

RESULTS

Depending on the timing of sowing, the sowing-seedling period ranged from 16 to 21 days and occurred at GDD (>10°C) from 33.4 to 153.7°C and total precipitation from 7.1 to 31.3 mm (Fig. 1). The longest sowing-germination period was observed with the variants sown from 1st to 3rd ten-day periods of April, at later sowing dates this period decreased.

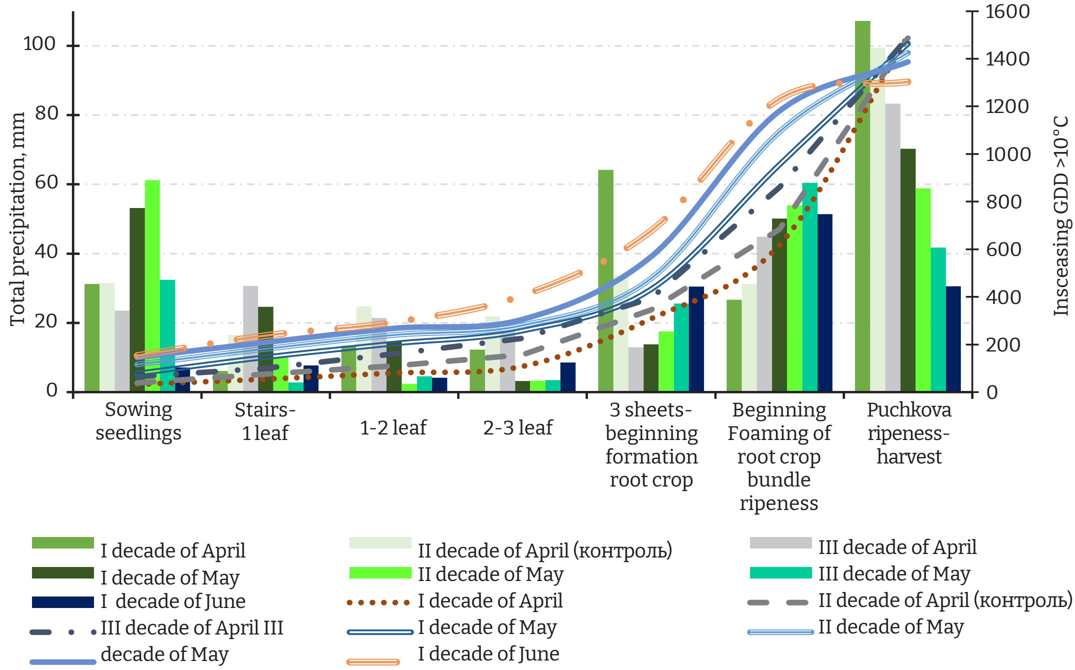

Figure 1. GDD > 10°C and precipitation required for the phenological phases of growth and development of parsnip at different sowing dates (average for 2015-2017)

The appearance of the first true leaf is recorded on 6-9 days after germination. This period was characterised by GDD (> 10°C) ranging from 21.7-84.2°C and precipitation of 2.8-30.7 mm. The phenological phase of the second true leaf is observed 4-8 days after the appearance of the first true leaf. During this phenological phase, the period was characterised by temperatures (>10°C) of 26.1-59.8°C and precipitation of 2.4-24.7 mm.

The period 2-3 of the true leaf lasted 3-8 days and occurred at GDD (> 10°C) of 27.7-112.5°C and precipitation of 3.2-21.8 mm.

The beginning of root crop formation was observed in 17-23 days after the appearance of the third true leaf. During this phenological phase, the period was characterised by GDD (> 10°C) of 168.61-270.8°C and precipitation of 13.0-64.1 mm.

The phenological phase of the beginning of the formation of the root cropbunch ripeness lasted 28-51 days and occurred at GDD (>10°C) of 309.9-616.1°C and precipitation of 26.7-60.4 mm. This period was the shortest for the variants of sowing from 1st to 2nd ten-day periods of April, and at later sowing dates this period increased.

The period of germination-technical ripeness lasted 110-165 days and occurred at GDD (> 10°C) of 1102.4-1439.0°C and precipitation of 128.1-225.2 mm.

Parsnip leaves are a very important organ of the plant, in which organic substances are formed in the process of photosynthesis, due to which the weight of the root crop increases and sugar accumulates.

Leaf weight on July 1 ranged from 11 to 82 g, on August 1 – from 16 to 138, on September 1 – from 52 to 217, and on October 1 – from 63 to 109 g. The maximum growth of leaves with an index of 1.5-4.5 g / day was observed in the second half of August, then the formation of new leaves decreased, and the old ones died off.

On July 1, in the variants sown in April and May, the weight of root crops was 4-37 g. On August 1, the previous figure ranged from 6 to 88 g, on September 1 from 24 to 179 g, and on October 1 from 69 to 236 g.

The maximum growth of root crops in the variants sown in April was observed in the second half of August with an indicator of 2.9-3.5 g/day, sown in May, respectively, in early September – 2.1-2.7 g/day, sown in June, respectively, in the second half of September – 1.9 g/day. The ratio of leaf mass to root crop on July 1 ranged from 2.2 to 2.8, on August 1 – from 1.6 to 2.7, on September 1 – from 1.2 to 2.2, on October 4 – from 0.5 to 0.9.

The variant sown in the 1st ten-day period of April provided a high yield of root crops of 50.3 t/ha, which is 5.3 t/ha or 11.8% significantly more than that of the control variant (Fig. 2). A significant decrease in yield was observed for later sowing in comparison with the control, namely: during the 3rd ten-day period of April – by 3.5 t/ha, or 7.7%, during the 1st ten-day period of May – by 8.8 t/ha, or 19.6%, during the 2nd ten-day period of May – by 17.4 t/ha, or 38.6%, during the 3rd ten-day period of May – by 23.0 t/ha, or 51.1%, during the 1st ten-day period of June – by 31.7 t/ha, 70.6% compared to the control.

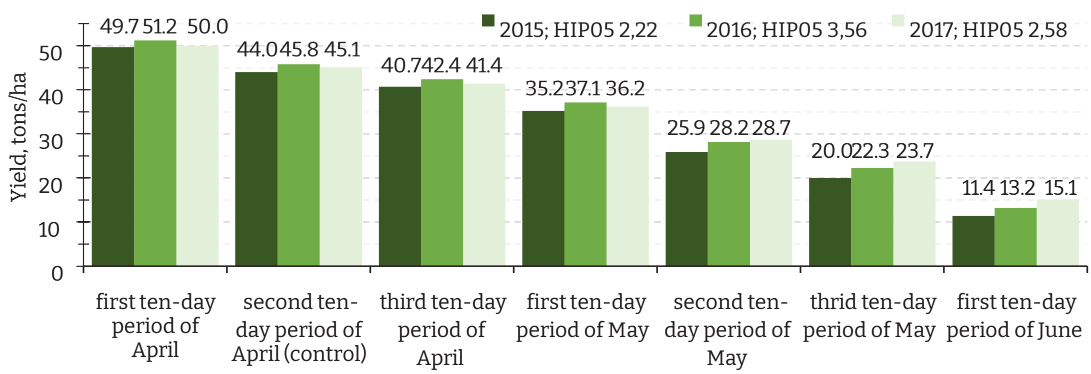

Figure 2. The yield of parsnip roots depending on the time of sowing, tons/ha

A strong direct correlation (r = 0.74-0.99) was found between the growing season and yield, root mass, marketability, and biochemical parameters, namely: dry matter, dry soluble matter, sugars, vitamin C. An inverse correlation (r = -0.98) was observed between the duration of the growing season and nitrates.

Increasing the growing season by 10 days increases the yield up to 6.9 t/ha, marketability up to 2.7%, root weight up to 31 g, dry matter content up to 0.7%, dry soluble matter up to 0.3%, sugars up to 0.5%, vitamin C up to 0.8 mg/100 g and reduces the nitrate content to 8.4 mg/kg.

Leaf area, photosynthetic potential, and net photosynthetic productivity are strongly directly related (r = 0.92-0.98) to yield.

For increasing the leaf surface area to 1.0 thousand $m^2$the yield is also growing up to 0.7 t/ha. Increasing the photosynthetic potential to 0.05 million m^2 days/ha increases the yield to 0.2-1.2 t/ha. Also, the yield increases to 0.3-0.7 t/ha with an increase in net photosynthetic productivity to 0.05 g/m^2 per day.

CONCLUSIONS

An efficient and cost-effective lever for stabilising yields in vegetable production is to use varieties with the high genetic potential of the crop, resistant to diseases and pests and adapted to growing conditions. The creation of a variety, its testing and cultivation are influenced by abiotic factors, and the interaction between these factors and the genetic system of the variety determines its value. The molecular knowledge on plant responses to abiotic stress is promising for further study and is likely to advance crop resilience to climate change and increase the economic efficiency of production. The vegetation period in parsnip lasted 110-165 days and occurred at GDD (> 10°C) of 1102.4-1439.0°C and precipitation of 128.1-225.2 mm. Yields at different sowing dates ranged from 13.2 to 50.3 t/ha.

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Вплив абіотичних факторів на ріст і розвиток рослин пастернаку

Анотація. Основними факторами, що впливають на ріст рослин, збільшення врожаю та його якісні характеристики, є біотичні та абіотичні чинники. Поєднання абіотичних стресів, таких як посуха та спека, мають значно більший вплив на врожайність та якість продукції. Реакція рослин на ці стреси може відрізнятися залежно від виду та стадії розвитку. Розуміння механізмів і способів захисту рослин від стресів стало життєво важливим для підвищення врожайності та якості продукції пастернаку в умовах мінливого клімату. Метою дослідження було визначення впливу абіотичних факторів (температури та опадів) на врожайність, тривалість фенологічних фаз росту і розвитку рослин, динаміку наростання листкової та кореневої маси пастернаку в умовах Правобережного Лісостепу України. Дослідження проводили в польовому досліді кафедри овочівництва і закритого ґрунту ННДІ "Плодоовочевий сад" НУБіП України в умовах Правобережного Лісостепу України протягом 2015-2017 рр. Площа облікової ділянки становила 11,3 $м^2$, повторність досліду - чотириразова. Розміщення варіантів - систематичне. Дослідженнями встановлено, що найкоротший період сівба-сходи тривав 16 днів у варіантах, де сівбу проводили у 3-й декаді травня та 1-й декаді червня. Значне запізнення на 21 день у цьому періоді було відмічено за сівби з 1 по 3 декаду квітня. Тривалість періоду від початку формування коренеплодів до пучкової стиглості була найкоротшою за сівби в 1-й декаді квітня – 28 днів, а найдовшою за сівби в 1-й декаді червня – 51 день. Вегетаційний період коливався від 110 до 165 днів і характеризувався середньодобовою температурою (> 10 °С) 1102,4-1439,0 °С та кількістю опадів 128,1-225,2 мм. Після сівби у квітні інтенсивний приріст коренеплодів від 2,9 до 3,5 г/добу спостерігався у другій половині серпня. За сівби у травні найбільший приріст коренеплодів від 2,1 до 2,7 г/добу відмічено у першій половині вересня. Так, за сівби в 1-й декаді червня цей показник був найвищим у другій половині вересня (1,9 г/добу). Варіант із сівбою в 1-й декаді квітня забезпечив високу врожайність коренеплодів – 50,3 т/га, що на 5,3 т/га, або на 11,8%, достовірно більше, ніж на контрольному варіанті. За сівби в наступні строки спостерігалося суттєве зниження врожайності порівняно з контролем, а саме: за сівби у 3 декаді квітня - на 3,5 т/га, або на 7,7%, за сівби у 1 декаді травня - на 8. 8 т/га, або 19,6%, за 2 декаду травня – на 17,4 т/га, або 38,6%, за 3 декаду травня - на 23,0 т/га, або 51,1%, за

1 декаду червня - на 31,7 т/га, або 70,6% порівняно з контролем. Встановлено сильний прямий кореляційний зв'язок (r = 0,74-0,99) між тривалістю вегетаційного періоду та врожайністю, масою коренеплодів, товарністю і біохімічними показниками, а саме: суха речовина, суха розчинна речовина, цукри, вітамін С. Зворотний кореляційний зв'язок (r = -0,98) спостерігався між тривалістю вегетаційного періоду та вмістом нітратів. Збільшення вегетаційного періоду на 10 днів підвищує врожайність до 6,9 т/га, товарність до 2,7%, масу коренеплоду до 31 г, вміст сухої речовини до 0,7%, сухої розчинної речовини до 0,3%, цукрів до 0,5%, вітаміну С до 0,8 мг/100 г та знижує вміст нітратів до 8,4 мг/кг. Площа листкової поверхні, фотосинтетичний потенціал та чиста продуктивність фотосинтезу мають сильний прямий зв'язок (r = 0,92-0,98) з урожайністю. Зі збільшенням площі листкової поверхні до 1,0 тис. м2 врожайність також зростає до 0,7 т/га. Збільшення фотосинтетичного потенціалу до 0,05 млн м2 днів/га збільшує врожайність до 0,2-1,2 т/га. Також врожайність зростає до 0,3-0,7 т/га при збільшенні чистої продуктивності фотосинтезу до 0,05 г/м2 на добу. Молекулярні знання про реакцію рослин на абіотичний стрес є перспективними для подальшого вивчення і, ймовірно, сприятимуть підвищенню стійкості сільськогосподарських культур до зміни клімату та економічній ефективності виробництва

Ключові слова: пастернак, температура, опади, врожайність, ріст коренів і листя