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**MODERN APPROACHES TO
SOYBEAN CULTIVATION
TECHNOLOGY IN EUROPEAN
COUNTRIES**

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The article examines the specific features of soybean cultivation in European countries, as well as certain aspects of this sector within Ukraine's agricultural sector. The role of this crop in Europe as a source of protein for livestock production is highlighted. Researchers recommend paying particular attention to cultivar selection, as soybean productivity, seed quality, and the economic efficiency of its cultivation depend largely on the cultivar. It has been established that when cultivars are transferred to different soybean-growing latitudes - from south to north or in the opposite direction - the maturity group and productivity level of the crop generally change. Given this biological characteristic, it is possible to practically regulate certain morphological traits, including plant height (through internode elongation), leafiness, and oil content, while protein content decreases. Particular emphasis is placed on the key elements of soybean cultivation technology in European countries. Today, the European approach to soybean cultivation focuses on environmental safety (the European Green Deal), adaptation to climate change, and maximum biologization. The main direction involves avoiding GMOs, imposing strict restrictions on pesticide use, ensuring comprehensive product traceability, and applying biological products.

Thus, biologization as a component of modern production technologies provides farms with significant advantages. Direct cost savings: the cost of a per-hectare application of a high-quality inoculant is several times lower than the cost of an equivalent amount of mineral nitrogen fertilizers (ammonium nitrate and urea). Improved crop quality: biologically fixed nitrogen is supplied to the plant evenly throughout the growing season, thereby directly increasing the protein content of soybean grain. Preservation of soil fertility: unlike mineral fertilizers, biologically fixed nitrogen does not acidify the soil, is not leached into groundwater, and does not adversely affect the natural soil microbiome.

Keywords: soybean, cultivar, crop, cultivation technology, biologization, environmental protection.

Table 2, Ref. 14.

Introduction. Soybean (*Glycine max* (L.) Merrill) is a grain legume crop of strategic importance for the 21st century and is currently at the center of global agricultural research and production. Over the past 50 years, global soybean production has increased almost tenfold, substantially outpacing population growth. Soybean ranks fourth worldwide in terms of production volume and serves as an important source of plant protein and biologically fixed nitrogen: well-developed soybean crops accumulate approximately 155–198 kg/ha of nitrogen, thereby meeting 65–80% of their own nitrogen requirements, while a significant proportion of the remainder is left in the soil. Therefore, soybean is considered one of the best preceding crops in crop rotations [1].



Analysis of recent research and publications. Only about 3 million tonnes of soybeans are produced annually in the EU, while approximately 13 million tonnes of soybean beans and 15 million tonnes of soybean meal (in soybean-equivalent terms) are imported. Thus, the European Union has an additional overall demand for approximately 33 million tonnes of soybeans, making it highly dependent on external supplies, particularly of energy resources and soybeans, which constitute a substantial part of its needs.

Consequently, the European Union is heavily dependent on imports, particularly with regard to protein feed for livestock production, in which soybean meal is a key component. Soybean meal is rich in protein and highly digestible, enabling the livestock sector to maintain its competitiveness in global markets. However, this requires a stable feed supply, which depends both on modern crop cultivation technologies and on weather conditions.

According to numerous studies, increasing gross soybean grain yields and the profitability of soybean production requires the development of cultivars with superior genetic potential and improved sowing qualities. The efficiency of soybean production compared with other field crops is determined primarily by yield, which is the most dynamic factor. Long-term experience of producers demonstrates that additional yields can be achieved through innovative technologies based on micronutrient fertilizers [2]. Scientists from economically developed countries, including France, the United Kingdom, Germany, and Switzerland, recommend combining micronutrient fertilizers with growth regulators, which can increase soybean yields by 20–30% [3; 4]. Therefore, the primary emphasis should be placed on high-yielding cultivars and technological factors of cultivation, regardless of soil and climatic conditions.

Climate change poses a serious threat to the planet, causing instability in crop production, including soybean seed production. Consequently, plant breeders have had to devote considerable time to developing new-generation cultivars adapted to stressful weather conditions [5]. At the same time, climate change creates opportunities for new approaches and innovations in the cultivation of agricultural crops, including soybean. Scientists should therefore implement a comprehensive set of innovative solutions at different stages of soybean production to ensure both higher yields and improved quality.

The stability of the crop production sector, elimination of protein deficiencies, expansion of fat resources, and accumulation of nitrogen reserves in the soil are directly associated with the cultivation of this crop.

Global soybean production has now reached a record 441 million tonnes, with this growth driven by strong demand for this oilseed crop. The largest production volumes are concentrated in just three countries: Brazil produces more than 153 million tonnes, ranking first globally; the United States produces approximately 116–121 million tonnes; and Argentina produces about 51 million tonnes. Numerous factors influence the success of soybean cultivation, including the proper selection of a cultivar and sowing date.

By shifting the sowing date, it is possible to regulate the availability of heat and moisture for crops under changing climatic conditions [6]. In addition to the sum of active air temperatures above 10°C, the optimal agroclimatic indicators of the soybean-growing zone for specific cultivar groups are as follows:

- early-maturing cultivars – 1,800–2,000°C;
- early-medium-maturing cultivars – 2,000–2,600°C;
- medium-maturing cultivars – 2,600–2,850°C;
- medium-late-maturing cultivars – 2,850–3,200°C;
- frost-free period – 130 days or more;
- total solar radiation during the growing season – 2,700–3,200 MJ/m²;
- photosynthetically active radiation (PAR) during the growing season – 1,200–1,500 MJ/ha;
- available soil moisture reserves in the 0–20 cm soil layer – 20–60 mm;
- hydrothermal coefficient – 1.1–1.7.

Soybean is a short-day crop: in order to enter the reproductive stage of development, it requires a specific ratio of light and dark periods during the day; therefore, it responds sensitively to light and day length. There is also a critical photoperiod within which flowering is possible: late-maturing cultivars flower when the day lasts 12–14 hours, medium-maturing cultivars at 17–18 hours, whereas early-maturing and ultra-early-maturing cultivars are day-neutral, even under continuous illumination.

The transfer of cultivars to other soybean-growing latitudes generally leads to changes in their maturity group and productivity level. Given this biological characteristic, it is possible to practically regulate plant height through internode elongation, as well as leafiness and oil content (with a simultaneous decrease in protein content): when a cultivar of a southern ecotype is moved to more northern latitudes, and conversely, when a cultivar of a northern ecotype is grown at southern latitudes [7, 8].

The cultivar has a significant influence on seed yield and quality; according to L. M. Sereda, its contribution to crop yield formation amounts to 30–35% [10]. Scientific observations indicate that among early-maturing soybean cultivars, Estafeta and Sprytна were the leaders in yield, with 3.70 t/ha, followed by Pallada at 3.67 t/ha, as well as Khvyliа and Olena at 3.40 t/ha. The highest protein content was recorded in Opus (46.0%), AAC Invest (44.5%), Sultana (43.5%), and ES Gladiator (43.0%), while the highest oil content was found in Almaz (25.5%) and Antratsyt (25.0%) [9]. According to other authors, almost half of the success of soybean cultivation depends on the correct selection of the cultivar [11–13].

New high-yielding soybean cultivars have made it possible both to expand the crop's cultivation range and to obtain high yields [14]. The extent to which a cultivar can be distributed is determined by its biological characteristics and environmental conditions. Therefore, each cultivar should be grown in the region or zone where its biological and genetic yield potential can be realized most effectively [15].

Research into how modern soybean cultivars realize their potential depending on sowing date and seeding rate and, consequently, plant density is valuable because it helps identify ways to maximize the realization of genetic potential and increase the plant's resistance, as a biological organism, to adverse environmental factors [16].

Materials and methods of research. The assessment and comparison of indicators of the key components of modern European agricultural practice were carried out using the comparative analysis method, which made it possible to identify the main differences between producing countries. The share of individual key components of modern European agricultural practice in total national output, as well as their positioning on the world market, was calculated using the structural analysis method.

Research results. During the period of global warming, the importance of cultivar selection has increased even further: air and soil temperatures are rising noticeably, while prolonged periods between rainfall events occur increasingly frequently. Such conditions cause stress in plants, sharply reduce their productivity, increase the spread of diseases and pests, and deteriorate product quality. Therefore, Ukrainian and European farmers must find responses to these environmental challenges and make appropriate decisions (*Table 1*).

Maximum biologization, adaptation to climate change, and environmental safety (the European Green Deal) are the foundations of soybean cultivation technology in Europe today. Its principal features include the use of biological products, strict restrictions on pesticide use, comprehensive product traceability, and the rejection of genetically modified organisms (GMOs).

Table 1

Advantages and Technological Challenges

Parameter	Advantages of Eco-Friendly Protection	Technological Challenges
Economics	Zero or minimal expenditure on expensive imported herbicides and insecticides.	Greater fuel consumption and the need for additional machinery passes across the field.
Agronomy	No phytotoxic stress in cultivated plants (no “herbicide injury”).	Strong dependence on weather conditions: mechanical cultivation is impossible during rainfall or severe drought.
Ecology	Preservation of beneficial pollinating insects and restoration of soil microflora.	Biological products require strict adherence to temperature conditions and UV protection.

Source: generated by the author

Among the key components of contemporary European agricultural practices are the following: *Precision agriculture*: GPS navigation enables precise seed placement and fertilizer application, while remote sensing (satellite imagery and drones) makes it possible to monitor crop conditions and detect pests or diseases at an early stage. Precision agriculture is a modern approach to agricultural production management based on the differentiated use of resources.

It relies on spatial data, thereby minimizing costs, protecting the environment, and maximizing crop yields from every square meter of a field. *Satellite monitoring and drones.* Satellite imagery regularly covers large areas; based on vegetation indices (e.g., (NDVI)), systems identify areas where crops lack moisture or nitrogen and assess the overall condition of crops. Drones (UAVs) perform targeted surveys of problem areas: multispectral cameras enable them to detect early signs of diseases and identify pest and weed infestations;

Precision seeding and fertilization: Seeders and spreaders controlled by prescription maps (Variable Rate Application, VRA technology) adjust application rates according to the fertility of a specific microzone using GPS navigation and variable-rate application;

Biologization of plant nutrition: To ensure that plants receive symbiotically fixed nitrogen and to reduce the need for mineral nitrogen fertilizers to a minimum, inoculants (the bacterium *Bradyrhizobium japonicum*) are widely applied in combination with protective polymers.

Environmental protection: Weeds are controlled mechanically using rotary and inter-row cultivators, thereby eliminating blanket chemical herbicide treatments, while bioinsecticides are used to control insect pests. Environmental sustainability requirements stipulate that, in accordance with new EU regulations (in particular, Regulation (EU) 2023/1115), every batch of soybeans must be traceable from the port to the specific geographic field of origin. This ensures full traceability and helps prevent deforestation.

Moisture conservation: Moisture accumulation is promoted through deep soil loosening (to a depth of 25–40 cm), which breaks up the plough pan, as well as through mulching and a transition to mini-till (minimum tillage) or no-till (*Table 2*).

Table 2

Comparison of the Water Balance of Different Technologies

Indicator	Conventional Plowing	Mini-Till / No-Till
Rainfall infiltration	Low (impeded by the plough pan)	High (due to drainage channels created by chisel plows and earthworm burrows)
Summer evaporation	Critically high (bare soil surface)	Minimal (protected by a layer of mulch)
Erosion resistance	Susceptible to wind erosion and soil washout	Complete protection against wind and heavy rainfall

Source: generated by the author

Benefits of transitioning to smart technologies. The comprehensive adoption of these technologies generates substantial economic savings: savings on fertilizers and plant protection products can reach 15–25% through targeted application, while fuel and seed costs are also reduced. Average crop yields increase by up to 4% in intensive farming operations and by up to 22% when farms move away from conventional methods.

In practice, these technologies are implemented through specialized software (such as EOSDA Crop Monitoring or its analogues), which collects historical data as well as information from drones and satellites and then displays the data directly on monitoring screens.

Conclusions. Thus, biologization as a component of modern production technologies provides farms with significant advantages. Direct cost savings: the cost of a per-hectare application of a high-quality inoculant is several times lower than the cost of an equivalent amount of mineral nitrogen fertilizers (ammonium nitrate and urea). Improved crop quality: biologically fixed nitrogen is supplied to the plant evenly throughout the growing season, thereby directly increasing the protein content of soybean grain. Preservation of soil fertility: unlike mineral fertilizers, biologically fixed nitrogen does not acidify the soil, is not leached into groundwater, and does not adversely affect the natural soil microbiome.

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АНОТАЦІЯ **СУЧАСНІ ПІДХОДИ ДО ТЕХНОЛОГІЇ ВИРОЩУВАННЯ СОЇ В** **КРАЇНАХ ЄВРОПИ**

В статті наведена інформація, щодо вирощування сої в країнах Європи та окремих елементів у аграрному секторі України. Висвітлено значення даної культури в країнах Європи, як білкового джерела у виробництві тваринницької продукції. При вирощуванні сої вчені рекомендують значну увагу приділяти вибору сорту від якого в подальшому залежить її продуктивність, якість насіння та економічна ефективність. Встановлено, що при умові перенесення сортів у інші соєсійні широти з півдня на північ і навпаки, як правило, призводить до зміни групи стиглості та рівня продуктивності культури. Враховуючи дану біологічну властивість є можливість практичного регулювання морфологічними ознаками, а саме збільшення висоти рослин завдяки видовженню міжвузля, облистяності та олійності при зменшенні вмісту білка. Окремо зосереджена увага на важливих елементах технології вирощування сої в країнах Європи, коли сучасна технологія вирощування сої в Європі фокусується на екологічній безпеці (Зелений курс ЄС), адаптації до змін клімату та максимальній біологізації. Головний вектор – відмова від ГМО, суворі обмеження на пестициди, глибока простежуваність продукції та використання біопрепаратів.

Отже, впровадження у сільськогосподарське виробництво біологізації, як фактору сучасних технологій, забезпечує господарству суттєві переваги: Прямі економії: вартість гектарної норми високоякісного інокулянта в рази нижча за вартість еквівалентної кількості азотних мінеральних добрив (селітри, карбаміду). Покращення якості врожаю: Симбіотичний азот надходить у рослину рівномірно протягом усього вегетаційного періоду, що безпосередньо підвищує рівень білка в зерні сої, збереження родючості ґрунтів: На відміну від мінеральних добрив, біологічний азот не закислює ґрунт і не вимивається в підземні води, зберігаючи природний мікробіом.

Ключові слова: соя, сорт, культура, технологія, біологізація, екологічний захист.

Табл. 2, Літ. 14.

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