AGROTECHNOLOGICAL AND ECONOMIC ASPECTS OF CULTIVATING MEDICINAL PLANTS IN EUROPEAN COUNTRIES: COMPARATIVE ANALYSIS AND DEVELOPMENT PROSPECTS

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Introduction

Medicinal plants play a significant role in modern medicine, the pharmaceutical industry, and traditional healthcare systems. They serve as a source of biologically active compounds widely used in the production of medicinal products, cosmetics, and dietary supplements. Due to the growing demand for natural products, interest in the cultivation of medicinal plants has been steadily increasing.

Europe is characterized by considerable diversity in natural and climatic conditions, which determines the specific features of cultivating medicinal crops in different regions. Climate, soil resources, moisture availability, and the length of the growing season directly affect plant productivity and the accumulation of active compounds. Therefore, cultivation technologies may differ significantly even within the same climatic zone [18; 23].

Ukraine, Poland, and Germany belong to the temperate climatic zone, which generally provides favorable conditions for the cultivation of a wide range of medicinal plants. However, each of these countries has its own specific agro-climatic resources and level of agricultural development, which determine the organization of production and the overall efficiency of the sector.

In Ukraine, the medicinal plant sector is characterized by significant natural potential and biodiversity, but it requires modernization and the implementation of advanced technologies. In Poland, there is active development of organic production and an export-oriented approach. Germany, in turn, is distinguished by a high level of technological advancement, standardization, and close integration with the pharmaceutical industry [24; 21].

The aim of this study is a comprehensive analysis of agrotechnological, climatic, and economic aspects of medicinal plant cultivation in European countries (using Ukraine, Poland, and Germany as examples), as well as the identification of key factors for improving production efficiency and substantiating development prospects for the sector.

To achieve this aim, the following research objectives were defined:

The objectives of the study include analyzing the impact of climatic conditions on the growth, development, and productivity of medicinal plants; investigating the specific features of medicinal plant cultivation in Ukraine; characterizing the current state and organizational-technological approaches in Poland; analyzing the high-tech model of production in Germany; conducting a comparative analysis of sector development; evaluating economic efficiency based on cost, profit, and profitability indicators; determining the impact of technological development on economic outcomes; examining the role of processing in value creation; analyzing the importance of organic production; assessing the role of state support; identifying key risks; and substantiating strategic directions for improving economic efficiency in Ukraine.

Climatic factors and their impact on medicinal plants. An important aspect of the influence of climatic conditions is the interaction between temperature regimes and soil moisture, which directly determines the intensity of physiological and biochemical processes in plants. The optimal combination of these factors ensures active root system development, improves nutrient uptake efficiency, and contributes to high productivity of medicinal crops.

Seasonal dynamics of climatic indicators are also of great importance, as they regulate the progression of phenological stages of plant development. Clearly defined seasonal patterns contribute to the harmonious progression of germination, vegetation, flowering, and fruiting processes. However, disruptions in seasonal rhythms caused by climate change may lead to desynchronization of biological processes and reduced productivity.

Special attention should be paid to microclimatic conditions, which are formed under the influence of local factors such as topography, hydrological features, soil cover, and vegetation. Even within a single climatic zone, these factors can create significant differences in temperature and moisture regimes, which must be considered when placing medicinal plant crops.

Climatic conditions largely determine technological approaches to cultivation. In regions with moisture deficits, irrigation and water-saving technologies become necessary, whereas in areas with excessive moisture, measures aimed at improving soil aeration and protecting plants from pathogens are required. Thus, climate acts as a key factor in shaping adaptive agrotechnologies.

It should also be noted that climatic conditions influence species composition and biodiversity of medicinal plants. Different climatic regions form specific phytocenoses characterized by species adapted to particular ecological niches. This determines both the diversity of medicinal raw materials and differences in their chemical composition and pharmacological activity.

Under modern conditions, the use of innovative technologies for monitoring climatic parameters is gaining increasing importance. The application of digital monitoring systems, geographic information technologies, and predictive models enables real-time analysis of climate changes and their impact on crop production. This creates conditions for improving the efficiency of medicinal plant cultivation and ensuring the stability of agricultural production under global climate transformations.

For a deeper understanding of the influence of natural conditions on the development of medicinal plants, it is advisable to examine in detail the main climatic factors and their role in shaping plant productivity. Each of these factors affects physiological processes–from seed germination to the accumulation of biologically active compounds. Summarizing these relationships makes it possible to determine the optimal conditions for producing high-quality medicinal raw materials (Table 1).

Table 1. Influence of Key Climatic Factors on Medicinal Plants

Climatic Factor	Impact on Plants	Consequences
Temperature	Regulates growth and development	Acceleration or inhibition of growth
Precipitation	Ensures water balance	Increase or decrease in yield
Light	Affects photosynthesis	Accumulation of biomass and active compounds
Air humidity	Determines conditions for disease development	Risk of fungal infections
Wind	Affects the physical condition of plants	Damage or improved aeration

The analysis of the main climatic factors shows that each of them has a complex and interrelated impact on the growth and development of medicinal plants. Temperature determines the rate of biological processes, precipitation ensures water balance, and light influences photosynthesis and the accumulation of active compounds. At the same time, air humidity and wind shape the conditions for the development or suppression of diseases and affect the physical condition of plants. Therefore, the optimal combination of these factors is a necessary condition for achieving high yields and obtaining high-quality medicinal raw materials.

To assess the specifics of medicinal plant cultivation in different countries, it is important to conduct a comparative analysis of their climatic conditions. Ukraine, Poland, and Germany belong to the temperate climatic zone; however, they differ significantly in terms of temperature regimes, precipitation levels, and humidity. The systematization of these indicators in tabular form makes it possible to clearly trace how the climatic features of each country influence agrotechnologies and risks in the cultivation of medicinal crops (Table 2).

Table 2. Comparison of climatic influence in Ukraine, Poland, and Germany

Factor	Ukraine	Poland	Germany
Temperature	High amplitude	Moderate	Mild
Precipitation	Uneven	Sufficient	Evenly distributed
Humidity	Medium	Moderate	High
Light regime	High solar radiation	Medium	Moderate
Risks	Droughts, frosts	Periodic fluctuations	High humidity, diseases

A comparative analysis of the climatic conditions of Ukraine, Poland, and Germany indicates significant differences in the natural prerequisites for the cultivation of medicinal plants. Ukraine is characterized by a more continental climate with increased risks of droughts and temperature fluctuations, Poland demonstrates relative stability and sufficient moisture supply, while Germany is distinguished by a mild and humid climate with an elevated risk of plant diseases. Therefore, the efficiency of medicinal crop cultivation in each country depends on the adaptation of agrotechnologies to specific climatic conditions.

Climatic conditions are among the most important factors determining the efficiency of medicinal plant cultivation. Temperature, humidity, precipitation, light regime, and wind conditions directly affect plant growth, development, and the accumulation of biologically active compounds.

The comparative analysis showed that Ukraine is characterized by a more continental climate with increased risks of droughts and temperature fluctuations. Poland has more stable conditions with sufficient moisture, which contributes to consistent yields. Germany is characterized by a mild and humid climate that provides favorable growing conditions but requires careful phytosanitary control of plants [18].

Thus, climatic conditions form the basic prerequisites for the cultivation of medicinal plants; however, their impact is realized through specific agrotechnologies and organizational approaches that differ depending on the country. In this regard, it is advisable to consider in more detail the features of medicinal plant cultivation in each of the studied countries.

Taking into account the above-mentioned climatic features, it is appropriate to first analyze the specifics of medicinal plant cultivation in Ukraine as a country with high natural potential [10; 13].

Features of medicinal plant cultivation in european countries

Ukraine has significant potential for the development of medicinal plant cultivation due to favorable natural and climatic conditions, advantageous geographical location, and high biodiversity. Different natural zones–Polissia, Forest-Steppe, and Steppe–form a wide range of ecological niches, creating favorable conditions for cultivating various medicinal plant species with different biological requirements.

One of the characteristic features of the sector is the combination of cultivated and wild-growing medicinal plants. A significant share of medicinal raw materials is still harvested from natural habitats, which reduces production costs but simultaneously creates risks of depletion of natural populations and necessitates the implementation of sustainable resource management principles.

The climatic conditions of Ukraine favor the cultivation of many traditional medicinal plants, including chamomile, peppermint, St. John’s wort, valerian, and calendula. Warm summers, sufficient solar radiation, and a long growing season ensure the intensive synthesis of biologically active compounds, thereby increasing the pharmacological value of raw materials.

At the same time, the uneven distribution of precipitation creates certain challenges for agricultural producers. Frequent droughts in southern and eastern regions can significantly reduce yields, which necessitates the implementation of irrigation systems, the use of drought-resistant varieties, and the optimization of cultivation technologies.

The soil cover of Ukraine, particularly chernozems, is characterized by high natural fertility, creating favorable conditions for cultivating medicinal plants with minimal use of mineral fertilizers. This opens up broad opportunities for the development of environmentally oriented and organic production.

The agrotechnology of medicinal plant cultivation in Ukraine is gradually improving. However, in many farms, traditional soil cultivation methods are still used, which do not always meet modern requirements for efficiency and environmental sustainability. At the same time, there is a gradual introduction of innovative technologies.

A characteristic feature is the relatively low level of mechanization of production processes compared to European Union countries. A significant proportion of operations, especially harvesting medicinal raw materials, is performed manually, which increases labor intensity and production costs.

The system of standardization and quality control of medicinal raw materials in Ukraine is at an active stage of development. Although international standards, including GACP, are being introduced, their application is not yet widespread, which affects the competitiveness of products in the international market.

Economic factors also play an important role in the development of the sector. Limited access to investment resources, insufficient technical equipment, and market instability restrain the expansion of medicinal plant production.

At the same time, there is a growing interest in organic medicinal plant production, which opens new opportunities for export and increasing added value. Ukraine has significant potential to occupy competitive positions in the European market of organic medicinal raw materials.

An important direction of development is also the regional specialization of production. In different natural and climatic zones, it is advisable to cultivate those medicinal plant species that are best adapted to local conditions, which allows increasing the efficiency of resource use.

Another important aspect is the development of scientific support for the sector. Research in the fields of breeding, agrotechnology, and pharmacognosy contributes to increasing yields, improving the quality of raw materials, and ensuring compliance with international standards.

In addition, the implementation of modern information technologies in production is becoming increasingly relevant. The use of monitoring systems, weather forecasting tools, and digital management of agricultural processes makes it possible to optimize production and reduce risks.

Special attention should be paid to the development of cooperation among producers of medicinal raw materials. The consolidation of small and medium-sized farms contributes to increased production efficiency, improved logistics, and stronger market positions [22; 23; 31].

In summary, despite the existing challenges, Ukraine has significant prospects for the development of medicinal plant cultivation. The implementation of modern agrotechnologies, improvement of standardization, development of organic production, and integration into the European market can ensure increased efficiency of the sector and its competitiveness at the international level.

Taking into account the identified features and challenges of medicinal plant cultivation in Ukraine, it is advisable to consider the experience of other European countries, particularly Poland, which demonstrates a more stable and well-organized model of sector development.

Poland is one of the leading countries in Europe in the field of medicinal plant cultivation, which is due to favorable natural and climatic conditions, effective state policy, and a high level of agricultural organization. As a result, the country occupies an important position in the European market of medicinal plant raw materials, meeting both domestic demand and ensuring significant export volumes.

The climate of Poland is moderate and transitional from maritime to continental, providing relatively stable conditions for the cultivation of most medicinal crops. Moderate temperatures, the absence of sharp climatic fluctuations, and sufficient precipitation throughout the year create favorable conditions for plant growth, development, and the accumulation of biologically active compounds. Such climatic stability minimizes the risks of yield losses and ensures predictability of production.

A wide range of medicinal plants is cultivated in Poland, among which chamomile, lemon balm, sage, valerian, and nettle occupy a prominent place. Considerable attention is also given to essential oil crops used in the pharmaceutical, cosmetic, and food industries. The diversity of crops is обусловлена both favorable natural conditions and established market demand for medicinal raw materials.

One of the key features is the high level of production organization. A significant number of farms operate under a contract system in cooperation with pharmaceutical enterprises and processing companies. This ensures stable product sales, guarantees compliance with quality standards, and reduces economic risks for producers.

Poland is actively developing organic medicinal plant production, which is an important segment of the agricultural sector. Cultivation without the use of synthetic fertilizers and pesticides makes it possible to obtain environmentally safe products that meet modern consumer requirements and have high demand in European and global markets.

An important characteristic is the high level of mechanization of production processes. The use of modern agricultural machinery and specialized equipment for sowing, cultivation, and harvesting contributes to reducing labor intensity, increasing productivity, and improving the quality of raw materials.

The system of standardization and quality control in Poland fully complies with European requirements. Producers adhere to international standards, including the principles of Good Agricultural and Collection Practices (GACP), which ensures the safety, effectiveness, and consistency of product quality.

State support plays a crucial role in the development of the sector. Agricultural producers receive financial subsidies, grants, and access to development programs that stimulate the implementation of innovative technologies and the expansion of medicinal plant cultivation.

Poland has a well-developed infrastructure for processing medicinal raw materials. A significant share of production undergoes primary and deep processing, including drying, extraction, and essential oil production. This increases the added value of products and strengthens the country's position in the international market.

An important feature of the Polish model is the close integration of medicinal plant production with scientific research. Research institutions actively work on breeding new varieties adapted to local conditions, improving productivity, and increasing the content of biologically active compounds.

In addition, considerable attention is paid to the development of cooperation among producers. The formation of farmer cooperatives contributes to more efficient use of resources, improved logistics, and stronger market positions.

Another important factor is the development of training and advisory systems for producers. Polish farmers have access to modern knowledge, technologies, and recommendations, which contributes to improving their professional competence and production efficiency [25; 52].

Overall, medicinal plant cultivation in Poland is characterized by a high level of organization, technological advancement, standardization, and export orientation. The combination of natural resources, innovative technologies, state support, and integration with the scientific sector ensures stable development and competitiveness of the industry. This experience can be effectively utilized by other countries, particularly Ukraine, to improve their own medicinal plant sector.

At the same time, an even higher level of development of medicinal plant cultivation is observed in Germany, where the sector is characterized by high technological advancement, innovation, and deep integration with the pharmaceutical industry.

Germany is one of the leading countries in Europe in the field of cultivation and processing of medicinal plants. A highly developed agricultural sector, a powerful pharmaceutical industry, and their close integration ensure the efficient functioning of the sector. This allows the country not only to meet domestic demand but also to play a significant role in the international market of medicinal plant raw materials.

The climate of Germany is predominantly temperate with a strong influence of maritime air masses, resulting in mild winters and moderately warm summers. The absence of sharp temperature fluctuations and the even distribution of precipitation throughout the year create stable conditions for plant growth, promote uniform development, and ensure the formation of high-quality raw materials.

A wide range of medicinal crops is cultivated in Germany, among which chamomile, St. John’s wort, lavender, calendula, and fennel are of particular importance. Considerable attention is also given to crops with a high content of essential oils, which are widely used in the pharmaceutical, cosmetic, and food industries. The selection of crops is based on a combination of agroecological conditions and market demand.

One of the key features is the high level of mechanization and automation of production. Modern machinery and specialized equipment are used at all stages of the production process–from soil preparation to harvesting and primary processing of raw materials. This ensures high productivity, reduces labor costs, and minimizes product losses.

Innovative agrotechnologies are widely implemented in Germany, including precision farming systems, automated irrigation, remote plant monitoring, and the use of digital platforms for agricultural management. These technologies allow for optimization of resource use, increased yields, and consistent product quality.

An important feature is the strict compliance with international quality standards, such as GACP (Good Agricultural and Collection Practices) and GMP (Good Manufacturing Practice). This ensures the safety, efficacy, and standardization of medicinal plant raw materials, which is critically important for pharmaceutical use.

The country has a well-developed quality control system at all stages of production. Seed selection, monitoring of cultivation conditions, harvesting, drying, and storage are carried out in accordance with strict regulations, which ensures a high level of trust in German products on the global market.

Germany possesses a strong research and development base that plays a key role in the advancement of the sector. Research institutions and universities are actively engaged in breeding new varieties of medicinal

plants, studying their chemical composition, and improving cultivation technologies. Close cooperation between science, production, and the pharmaceutical industry facilitates the implementation of innovations.

The economic model of the sector is focused on the production of high value-added products. A significant portion of medicinal raw materials undergoes deep processing within the country, including the production of extracts, essential oils, and finished medicinal products.

A notable feature is the high level of environmental responsibility in production. Germany actively implements the principles of sustainable development, including the rational use of natural resources, reduction of environmental impact, and the development of organic farming.

An important direction is the development of cooperation and integration among market participants. Producers, processing enterprises, and research institutions operate within a unified system, which contributes to increased efficiency and rapid implementation of innovations.

In addition, considerable attention is paid to the training of qualified personnel. Educational programs and professional training ensure a high level of competence among specialists working in the medicinal plant sector [24; 21].

Thus, medicinal plant cultivation in Germany is characterized by a high level of technological development, standardization, scientific support, and innovation. The combination of modern agrotechnologies, efficient production organization, and strict quality control allows the country to occupy leading positions in Europe and provide stable, competitive products that meet the highest international standards.

The analyzed features of medicinal plant cultivation in Ukraine, Poland, and Germany provide a basis for a comparative analysis aimed at identifying key differences and efficiency factors.

Comparative analysis of development

The cultivation of medicinal plants in European countries has both common features and significant differences, determined by a combination of natural, economic, and technological factors. Ukraine, Poland, and Germany belong to the same temperate climatic zone; however, the level of development of the medicinal plant sector in these countries differs significantly, reflecting the specifics of their economic development and agricultural policies.

First of all, it should be noted that Ukraine has significant natural potential due to the high fertility of soils, particularly chernozems, and the diversity of climatic conditions. This creates favorable conditions for cultivating a wide range of medicinal crops. However, in practice, this potential is not fully realized due to insufficient technical support, limited access to investment, and slow implementation of modern agrotechnologies.

Poland occupies an intermediate position between Ukraine and Germany, combining favorable natural conditions with a relatively high level of production organization. Active state support, an effective subsidy system, and export orientation contribute to the stable development of the sector. In addition, considerable attention is paid to compliance with quality standards and the implementation of innovative technologies.

Germany, in turn, represents an example of a high-tech and intensive approach to the cultivation of medicinal plants. The sector is closely integrated with the pharmaceutical industry, ensuring a full production cycle–from the cultivation of raw materials to the manufacturing of finished medicinal products. This enables the creation of high value-added products and ensures their competitiveness on the global market.

An important aspect is also the level of mechanization and automation of production. While in Ukraine a significant share of work is performed manually, Poland demonstrates a medium level of mechanization, whereas in Germany most technological processes are fully automated. This directly affects labor productivity, production costs, and product quality.

Significant differences are also observed in quality control systems. In Germany and Poland, international standards such as GACP and GMP are widely implemented, ensuring high-quality medicinal raw materials. In Ukraine, these standards are only gradually being introduced, which limits the potential for exporting products to the European market.

Special attention should be given to the role of state support. In European Union countries, particularly in Poland and Germany, the agricultural sector receives substantial financial support, which stimulates the development of medicinal plant cultivation. In Ukraine, however, state support is less systematic, which restrains the modernization of the sector.

An important direction is the development of organic medicinal plant production. In Poland and Germany, this segment is actively developing and has significant export potential. Ukraine also has favorable

conditions for the development of organic production; however, this direction requires further institutional and technological support.

No less important is the level of scientific support for the sector. In Germany, scientific research is an integral part of the production process; in Poland, it is actively implemented in practice, whereas in Ukraine, scientific potential is not utilized efficiently enough.

Another important aspect is the dynamics of sector development in recent years. Changes in cultivation areas, production volumes, and export levels reflect the general trends in the development of the sector in each country. In EU countries, there is a tendency toward stable or gradual growth of cultivation areas due to state support and high demand for products. In Ukraine, these indicators are more unstable and depend on the economic situation and investment activity.

For a more detailed analysis, it is advisable to examine the dynamics of cultivation areas of medicinal plants in the studied countries, which will make it possible to assess development trends, identify patterns, and determine prospects for further growth of the sector (Table 3).

Table 3. Dynamics of cultivation areas of medicinal plants (2019–2024), thousand hectares

Year	Ukraine	Poland	Germany
2019	32	28	15
2020	30	29	16
2021	27	30	17
2022	25	31	18
2023	26	32	19
2024	28	34	20

During the period 2019–2024, Ukraine experienced a decline in cultivation areas, particularly in 2020–2022, which is associated with economic challenges and climatic risks.At the same time, Poland and Germany demonstrate a steady increase in cultivation areas, indicating effective sectoral support and stable development conditions.

Another important indicator is the volume of medicinal raw material production, which reflects the efficiency of resource utilization and the level of technological development (Table 4).

Table 4. Production volumes of medicinal plants (2019–2024), thousand tons

Year	Ukraine	Poland	Germany
2019	45	50	40
2020	43	52	42
2021	40	55	45
2022	38	57	47
2023	41	60	50
2024	44	63	53

The analysis of the data for 2019–2024 shows that Poland occupies leading positions in terms of production volumes among the studied countries, while Germany demonstrates steady growth due to high productivity. In Ukraine, however, certain instability in production indicators can be observed.

Another important criterion is the level of yield, which reflects the efficiency of cultivation technologies and the quality of agrotechnical practices.

Therefore, the analysis of yield indicators provides a deeper understanding of the effectiveness of resource use and technological development in medicinal plant cultivation (Table 5).

Table 5. Average yield of medicinal plants (2019–2024), centners per hectare

Year	Ukraine	Poland	Germany
2019	14	18	22
2020	14	19	23
2021	13	20	24
2022	12	21	25
2023	13	22	26
2024	14	23	27

The presented data for 2019–2024 indicate that Germany demonstrates the highest yield levels, which can be explained by the use of advanced technologies and a high level of mechanization. Poland also shows a positive trend, while Ukraine lags behind in this indicator.

Thus, the comparative analysis shows that Ukraine has significant potential for the development of medicinal plant cultivation but requires modernization and the implementation of innovations. Poland serves as an example of an effective combination of natural resources and modern technologies, while Germany represents a leader in high-tech production and standardization. Further development of the sector in Ukraine is possible through the adaptation of European experience, increased investment, and improvement of quality management systems.

Alongside natural and technological aspects, economic evaluation of production is of great importance, as it allows for determining the efficiency of resource use and the feasibility of sector development.

Economic efficiency of medicinal plant cultivation

An important aspect of assessing the development of medicinal plant cultivation is the determination of its economic efficiency. The comparison of not only natural and technological conditions but also economic indicators allows for a more comprehensive evaluation of the level of sector development in the studied countries.

The economic efficiency of medicinal plant cultivation is one of the key indicators determining the feasibility of developing this sector within agriculture. It reflects the relationship between production costs and the results obtained in the form of profit, profitability, and added value.

Under modern economic conditions, efficiency is determined not only by economic indicators but also by environmental and social aspects. The cultivation of medicinal plants is often associated with the use of environmentally friendly technologies, which increases their market value but may also influence the cost structure.

The main indicators of economic efficiency include production cost, profitability level, profit per unit area, labor productivity, and the level of added value.

The costs of cultivating medicinal plants have a complex and multi-component structure and depend on several factors, including the biological characteristics of the crop, cultivation technology, the level of mechanization, and the natural and climatic conditions of a particular region. Cost formation occurs at all stages of the production process–from soil preparation to harvesting, processing, and product marketing.

Material costs constitute a significant share of the total production cost. These include expenses for seeds or planting material, which may vary considerably depending on the type and variety of medicinal plants. An important component is also the cost of mineral and organic fertilizers, which ensure optimal plant nutrition and contribute to increased yields. Plant protection products are used to control pests, diseases, and weeds, particularly in intensive production systems. A separate share of costs includes fuel and lubricants used in mechanized field operations.

Labor costs are one of the most significant components in medicinal plant cultivation. They include wages for manual labor, which is especially relevant during plant care and harvesting stages. Many medicinal crops require manual harvesting to preserve raw material quality, which significantly increases labor intensity. In addition, labor costs include payments to qualified specialists such as agronomists, technologists, and quality control personnel.

Technical costs are associated with the use of agricultural machinery and equipment. These include operating expenses and depreciation costs related to maintenance and renewal. The level of technical costs

largely depends on the degree of mechanization: in high-tech farms, these costs are higher but are offset by increased labor productivity.

Other costs include expenses for irrigation (especially in regions with insufficient moisture), drying and primary processing of medicinal raw materials, and transportation to storage or marketing points. Energy costs, packaging, and storage also play a significant role.

A specific feature of medicinal plant cultivation is the high level of labor intensity, especially during harvesting, which is due to the need to maintain the quality and integrity of plant raw materials. In many cases, the use of mechanized harvesting is limited due to the risk of damage or reduction in pharmacological value.

In addition, the cost structure is significantly influenced by the scale of production and the level of specialization. Large farms benefit from economies of scale, which reduce unit costs, while small farms often face higher costs due to limited access to modern equipment and resources.

An important factor is also the type of production–conventional or organic. Organic cultivation of medicinal plants is usually associated with higher costs due to restrictions on the use of chemical inputs and the need for alternative plant care methods. However, such products have a higher market value, which can compensate for increased costs.

Thus, the cost structure in medicinal plant cultivation is complex and depends on many interrelated factors. Its optimization is an important condition for increasing economic efficiency, which can be achieved through the implementation of modern technologies, increased mechanization, and rational use of resources.

Production cost is one of the key economic indicators that characterizes the efficiency of medicinal plant cultivation. It reflects the total expenses required to produce a unit of output and serves as the basis for pricing and determining the profitability of the sector.

The formation of the cost of medicinal plant raw materials depends on a complex set of factors, among which the biological characteristics of the crop, yield level, applied agrotechnologies, natural and climatic conditions, and production organization are of particular importance. The degree of mechanization and the use of modern technical equipment also have a significant impact.

One of the key factors in reducing production costs is increasing yield. Under equal costs per unit area, an increase in output leads to a reduction in unit production costs. However, achieving high yields often requires additional expenditures on fertilizers, plant protection products, and technological measures, which necessitates cost optimization.

Labor costs constitute a significant share in the cost structure of medicinal plant production, especially when harvesting is performed manually. This is a distinctive feature of the sector compared to conventional crop production. High labor intensity may lead to increased production costs, particularly under conditions of rising labor expenses.

The level of technological support also has a considerable impact on production costs. The use of modern machinery and innovative technologies allows for reducing labor costs, improving resource efficiency, and minimizing production losses. However, the implementation of such technologies requires significant investment, which may increase initial costs.

Production scale is another important factor. In large-scale farms, production costs are generally lower due to economies of scale, more efficient resource utilization, and the ability to implement advanced technologies. In small-scale farms, unit costs are often higher, which reduces their competitiveness.

The level of product processing also plays a significant role. The production of primary raw materials is characterized by lower added value, whereas further processing (drying, extraction, essential oil production) significantly increases economic efficiency and reduces dependence on market fluctuations.

The profitability of medicinal plant cultivation is an integral indicator reflecting the relationship between profit and costs. It allows for assessing the feasibility and efficiency of production. High profitability indicates efficient resource use and product competitiveness.

The level of profitability largely depends on market price conditions, product quality, and the level of processing. In countries with a well-developed processing industry, such as Germany, profitability is higher due to the production of high value-added products. In Poland, profitability is supported by state support and effective production organization.

In Ukraine, profitability is less stable and depends on various factors, including climatic conditions, access to investment, and the level of technological development. At the same time, favorable natural conditions create opportunities for increasing sector profitability, provided that production modernization is implemented.

An important direction for increasing profitability is the development of organic medicinal plant production. Organic products have a higher market price, which allows compensating for increased production costs. In addition, they enjoy stable demand on the international market.

Thus, production cost and profitability of medicinal plant cultivation are interrelated indicators that determine the economic efficiency of the sector. Their optimization requires a comprehensive approach, including the implementation of modern technologies, increased mechanization, development of processing, and adaptation of production to market requirements.

For the economic evaluation of medicinal plant cultivation, it is advisable to use a system of generalized indicators (Table 6) that make it possible to determine the level of costs, profit, and production efficiency. The main indicators include total production cost, unit cost, profit, and profitability level.

Total production cost is defined as the sum of all expenses associated with cultivation, harvesting, drying, primary processing, and transportation of products:

1. Total production cost:

$$Cp = Cm + Cl + Ct + Co$$

where: Cp – total production cost, UAH; Cm – material costs, UAH; Cl – labor costs, UAH; Ct – technical costs, UAH; Co – other costs, UAH.

2. Unit cost of production:

$$Cu = Cp / Q$$

where: Cu – unit cost, UAH/t; Cp – total production cost, UAH; Q – production volume, t.

3. Revenue:

$$R = Q \times P$$

where: R – revenue, UAH; Q – volume of sold products, t; P – price per ton, UAH.

4. Profit:

$$Pr = R - Cp$$

where: Pr – profit, UAH; R – revenue, UAH; Cp – total production cost, UAH.

5. Profitability level:

$$Prof = (Pr / Cp) \times 100\%$$

where: Prof – profitability level, %; Pr – profit, UAH;Cp – total production cost, UAH.

The use of these formulas allows for a comprehensive assessment of the economic efficiency of medicinal plant cultivation. The calculation of total cost, unit cost, revenue, profit, and profitability provides an objective basis for evaluating production performance and identifying key factors influencing efficiency.

These indicators serve as an important tool for economic analysis, enabling both the assessment of current production conditions and the justification of management decisions aimed at cost optimization, productivity improvement, and quality enhancement. This is particularly relevant in a market economy, where competitiveness depends on achieving an optimal balance between costs and results.

Furthermore, the analysis of cost and profitability allows for comparison of different medicinal crops, identification of the most profitable production directions, and development of strategic approaches for sector advancement. This is especially important for Ukraine, which possesses significant natural potential but requires improvements in technological development and resource efficiency.

Thus, the systematic application of economic calculations is essential for increasing efficiency, ensuring sustainable development, and integrating medicinal plant cultivation into the international market.

Table 6. Example of calculating the cost and profitability of medicinal plant cultivation

Indicator	Nominal value
Cultivation area, ha	10
Yield, t/ha	2.5
Gross output, t	25
Material costs, UAH	180,000
Labor costs, UAH	120,000
Technical costs, UAH	90,000
Other costs, UAH	60,000
Total production cost, UAH	450,000
Selling price per 1 t, UAH	25,000
Sales revenue, UAH	625,000
Profit, UAH	175,000
Unit cost per 1 t, UAH/t	18,000
Profitability, %	38.9

In the presented example, the cultivation area of medicinal plants is 10 hectares, and the average yield is 2.5 t/ha, resulting in a gross output of 25 tons of products. The total production cost amounts to UAH 450,000, with the largest share consisting of material and labor costs.

Given a selling price of UAH 25,000 per ton, total revenue amounts to UAH 625,000. Accordingly, profit equals UAH 175,000. The unit cost of production is UAH 18,000 per ton, and the profitability level is 38.9%, which indicates a relatively high level of economic efficiency.

The presented example is conditional; however, it demonstrates the general approach to the economic evaluation of medicinal plant cultivation. In real conditions, the values of indicators may vary depending on the type of crop, growing region, weather conditions, technological support, and market price.

The use of cost, profit, and profitability formulas makes it possible to objectively assess the economic efficiency of medicinal plant cultivation. Such calculations are an important tool for managerial decision-making, cost planning, determining the feasibility of cultivating specific crops, and increasing overall sector profitability.

Economic efficiency directly depends on the level of technological support in production, which necessitates a detailed analysis of the impact of modern technologies.

Factors increasing efficiency

Technological development is one of the key factors in increasing the economic efficiency of medicinal plant cultivation. The level of implementation of modern agrotechnologies directly affects production productivity, product quality, cost levels, and the competitiveness of the sector in both domestic and international markets.

The introduction of innovative technologies allows for optimization of all stages of the production process–from soil preparation to harvesting and primary processing of medicinal raw materials. This ensures more rational use of material, labor, and technical resources, ultimately contributing to reduced production costs and increased profitability.

The main advantages of modern technologies include reduced resource consumption through precise application of inputs, increased yields, improved product quality, reduced losses during harvesting and storage, and decreased labor costs due to automation.The implementation of precision agriculture technologies is of particular importance. These include the use of digital monitoring systems, GPS navigation, sensor technologies, and data analytics. Such approaches allow for accounting for soil heterogeneity, optimizing the application of inputs, and improving land-use efficiency.

In Germany, precision agriculture is widely applied and significantly increases the efficiency of medicinal plant production. Automated management systems, modern machinery, and a high level of digitalization ensure stable yields and high product quality.

In Poland, automated cultivation systems are actively implemented, including modern seeders, irrigation systems, and mechanized harvesting. This reduces labor intensity and increases production efficiency, although the technological level is somewhat lower than in Germany.

In Ukraine, the process of technological modernization is still developing. Many farms continue to use traditional cultivation methods, which limits productivity and efficiency. However, gradual implementation of modern technologies, including irrigation systems, elements of precision agriculture, and improved plant varieties, is being observed.

An important aspect is also the impact of technological level on environmental sustainability. Modern technologies make it possible to reduce negative environmental impacts by decreasing the use of chemicals, optimizing water consumption, and implementing resource-saving technologies. This is especially relevant in the context of the development of organic medicinal plant production.

In addition, technological development contributes to increased production stability. The use of modern weather forecasting systems, plant monitoring, and risk management tools helps minimize the impact of adverse factors and ensures more predictable production outcomes.

Thus, the level of technological support is one of the key determinants of the economic efficiency of medicinal plant cultivation. The implementation of innovative agrotechnologies, increased mechanization, and digitalization create conditions for higher productivity, lower costs, and improved competitiveness of the sector.

Alongside technological development, the level of product processing is also an important factor influencing economic efficiency.

One of the key factors in increasing the economic efficiency of medicinal plant cultivation is the level of product processing. It is the degree of processing that determines the amount of added value generated at each stage of the production chain–from plant cultivation to the final pharmaceutical product.

Several levels of medicinal plant processing can be distinguished, including raw materials as the lowest value category, dried products as a form of primary processing, extracts and essential oils as products of deeper processing, and finished medicinal products representing the highest level of value creation represent the highest level of processing, ensuring maximum economic benefit due to the high market value of the final product.

An increase in the level of processing directly contributes to higher economic efficiency. The transition from selling raw materials to deep processing not only increases profit but also reduces dependence on raw material price fluctuations, which is an important factor for sector stability.

In Germany, most medicinal plant products undergo deep processing within the country. This ensures the formation of high added value, supports the development of the pharmaceutical industry, and strengthens the country's position in the international market. The production process is highly integrated, allowing quality control at all stages and ensuring compliance with international standards.

In Poland, there is also active development of processing infrastructure, particularly in drying, extraction, and essential oil production. This contributes to increased competitiveness and export orientation of production.

In Ukraine, however, the export of medicinal plant raw materials without sufficient processing predominates, significantly limiting the potential for value-added creation. As a result, a considerable share of profits is generated outside the country, where further processing takes place.

An important direction for improving economic efficiency in Ukraine is the development of processing capacities, including the establishment of enterprises for the production of extracts, essential oils, and finished medicinal products. This will not only increase producers' income but also stimulate the development of related industries, job creation, and overall economic growth [8; 9; 31; 44].

Thus, the level of processing of medicinal plants is one of the key factors in the formation of added value and economic efficiency. Deepening product processing is an important strategic direction for the development of medicinal plant cultivation, especially for countries with high natural potential, such as Ukraine.

A separate promising direction for improving efficiency is the development of organic medicinal plant production.

Organic medicinal plant cultivation is one of the most promising directions in the modern agricultural sector, driven by increasing demand for environmentally friendly products and stricter requirements for the quality of medicinal raw materials. Cultivation under organic standards involves refusal from the use of synthetic fertilizers, pesticides, and other chemicals, which contributes to environmental protection and improved product safety.

The economic advantages of organic production include higher product prices, growing demand in domestic and international markets, access to European markets, and increased competitiveness due to compliance with international standards.

An important feature of organic medicinal plant cultivation is its close connection with the principles of sustainable development. The use of environmentally safe technologies contributes to preserving soil fertility, biodiversity, and natural resources, which has long-term economic significance.

In Poland and Germany, organic medicinal plant production is actively supported by the state through subsidies, grants, and development programs. This encourages producers to transition to organic technologies and expand production volumes. In addition, these countries have established effective certification and quality control systems.

In Ukraine, organic medicinal plant cultivation is still in the development stage. Despite significant natural potential and favorable conditions for environmentally friendly production, its development is constrained by limited access to financing, insufficient institutional support, and difficulties in entering international markets.

The prospects for the development of organic medicinal plant production in Ukraine are associated with integration into the European market, improved standardization, and the implementation of modern technologies. The expansion of this segment will increase economic efficiency, boost exports, and strengthen the position of Ukrainian producers in the global market [6; 41; 20].

Thus, organic medicinal plant cultivation is an important direction for increasing economic efficiency, combining economic benefits with environmental sustainability and aligning with modern trends in agricultural development.

An important institutional factor in the development of the sector is state support.

State support is one of the key factors ensuring the economic efficiency of medicinal plant cultivation. It creates favorable conditions for sector development, stimulates investment activity, promotes the implementation of innovative technologies, and enhances the competitiveness of products in both domestic and international markets.

In European Union countries, state support for medicinal plant cultivation is implemented through a set of instruments, including:

State support is implemented through a range of instruments, including subsidies, grants, cost compensation mechanisms, and long-term development programs aimed at modernizing the agricultural sector.

Thanks to such a support system, conditions for stable development of medicinal plant cultivation are created in EU countries. Producers are able to reduce financial risks, implement modern technologies, and focus on producing high value-added products.

In Germany, state support is closely linked with scientific research and innovation, enabling the integration of medicinal plant production with the pharmaceutical industry. In Poland, European funds play a significant role, being directed toward the development of organic production, modernization of the technical base, and improvement of product quality.

In Ukraine, state support for medicinal plant cultivation remains limited and lacks a systemic character. Existing programs often do not account for the specific features of this sector or suffer from insufficient funding. This complicates the implementation of modern technologies, restrains the development of processing, and reduces the investment attractiveness of the industry.

Moreover, the absence of a clear state strategy for the development of medicinal plant cultivation leads to fragmented support measures and insufficient coordination between producers, research institutions, and processing enterprises. This negatively affects the overall efficiency and competitiveness of the sector.

At the same time, Ukraine has significant potential to improve its system of state support. The introduction of comprehensive development programs, stimulation of investment, support for organic production, and integration into European markets can substantially improve the situation.

In conclusion, state support acts as a decisive factor in shaping the economic efficiency of medicinal plant cultivation, and its consistency and scale directly influence the level of sector development and its competitive position in the international market.

The generalization of the identified trends makes it possible to determine the main directions for increasing economic efficiency in the sector.

Improving the economic efficiency of medicinal plant cultivation is one of the key tasks for sector development under modern conditions. It requires a comprehensive approach that encompasses both technological and organizational-economic aspects of production.

To achieve a high level of efficiency, it is necessary to implement modern agrotechnologies, develop processing of medicinal plant raw materials, support organic production, integrate into European markets, and promote cooperation among producers.

A comparative analysis of the economic efficiency of medicinal plant cultivation in different countries makes it possible to identify key factors determining sector competitiveness. Ukraine, Poland, and Germany share similar natural conditions but differ significantly in the level of economic organization and technological development.

In Ukraine, medicinal plant cultivation is predominantly extensive in nature. Production is mainly focused on raw materials with minimal processing, which limits the formation of high added value. In addition, insufficient mechanization, limited access to investment, and market instability hinder sector development and reduce efficiency.

Poland demonstrates a more balanced development model, combining favorable natural conditions, state support, and modern production organization. The active implementation of technologies, development of organic production, and export orientation ensure a stable level of economic efficiency.

Germany represents a highly efficient economic model based on innovation, automation, and deep product processing. Production processes are characterized by a high level of technological advancement, while close integration with the pharmaceutical industry ensures the creation of maximum value-added products.

In this context, the key directions for improving the efficiency of medicinal plant cultivation in Ukraine include production modernization, development of processing infrastructure, implementation of innovative technologies, and strengthening of state support. An important role is also played by adaptation to international quality standards and expansion into foreign markets [13; 43; 55].

Summarizing the above, it can be stated that increasing the economic efficiency of medicinal plant cultivation requires a systemic approach that combines technological development, organizational transformation, and active integration into the international economic environment, ensuring sustainable sector growth and competitiveness.

The economic efficiency of medicinal plant cultivation largely depends on the level of risks associated with the production process. The presence of various risks may lead to reduced yields, deterioration of product quality, increased costs, and instability of producers' income.

The main risks in medicinal plant cultivation include climatic, market, technological, and financial risks, each of which can significantly affect production efficiency and stability.

In addition, organizational risks related to imperfect production management and institutional risks caused by instability of the regulatory framework are also important.

In Ukraine, the level of risks in medicinal plant production is significantly higher than in European Union countries. This is due to greater dependence on climatic conditions, insufficient agricultural insurance systems, limited state support, and unstable market environments.

In Poland and Germany, risks are largely minimized due to the use of modern technologies, developed insurance systems, effective state support, and stable economic policies. Moreover, producers have better access to information resources, weather forecasts, and market analytics, allowing for more effective risk management.

An important direction for improving economic efficiency is the implementation of risk management systems, including production diversification, the use of insurance instruments, the adoption of modern technologies, and adaptation to climate change. This helps to reduce the negative impact of risks and ensure production stability.

Summarizing the above, it should be emphasized that the level of risks is one of the key determinants of the economic efficiency of medicinal plant cultivation. Their timely identification and minimization create the necessary conditions for stable sector development and increased competitiveness.

The development of medicinal plant cultivation in Ukraine requires the definition of clear strategic priorities aimed at improving economic efficiency, competitiveness, and integration into the global market. In the context of growing demand for medicinal plant raw materials and plant-based products, the formation of a long-term development strategy becomes particularly important.

The key directions for Ukraine's development include:

- the development of processing of medicinal plant raw materials, enabling the transition from raw material exports to the production of high value-added products, including extracts, essential oils, and finished medicinal products;
- attraction of investments necessary for production modernization, upgrading of technical infrastructure, implementation of innovative technologies, and development of processing capacities;
- improvement of the standardization and quality control system, particularly through the implementation of international standards (GACP, GMP), which is essential for access to European markets and increasing trust in Ukrainian products;
- strengthening of state support, including financial incentives, development programs for producers, export promotion, and the creation of a favorable institutional environment.
- In addition to these directions, the development of the research and innovation base is of great importance, as it enables the creation of new medicinal plant varieties adapted to Ukrainian conditions and the improvement of cultivation technologies. The development of cooperation among producers, processing enterprises, and research institutions also plays a significant role in improving resource efficiency.

Another important strategic direction is the development of organic medicinal plant production, which has significant export potential and corresponds to modern trends in agricultural development. The use of environmentally friendly technologies will enhance the competitiveness of Ukrainian products in the international market.

Furthermore, an essential condition for sector development is integration into international markets, which involves harmonization of standards, participation in international programs, and expansion of export opportunities. This will allow Ukrainian producers to strengthen their position in the global market for medicinal plant products [50; 37].

It is important to emphasize that the implementation of strategic directions for the development of medicinal plant cultivation in Ukraine requires a comprehensive approach that combines technological modernization, institutional support, and active integration into the global economic space. This will ensure sustainable sector growth and increased economic efficiency.

Conclusions

The conducted research presented in this monograph made it possible to comprehensively analyze the agrotechnological, climatic, and economic features of medicinal plant cultivation in European countries, particularly in Ukraine, Poland, and Germany. The obtained results indicate that medicinal plant cultivation is an important component of the agricultural sector, combining economic feasibility with environmental significance and the pharmacological value of products.

The study established that climatic conditions play a decisive role in shaping both the yield and quality of medicinal raw materials. Temperature regimes, precipitation levels, light conditions, and air humidity directly influence plant physiological processes and the accumulation of biologically active compounds. At the same time, production efficiency largely depends on the ability to adapt agrotechnologies to specific natural and climatic conditions.

The comparative analysis demonstrated that Ukraine has significant natural potential due to fertile soils and diverse climatic zones. However, this potential is not fully realized due to insufficient technological support, limited access to investment, and weak integration with the processing industry. Poland demonstrates a more balanced development model, combining natural resources, state support, and modern technologies. Germany serves as an example of a highly efficient, innovative, and integrated model, where medicinal plant production is closely linked with the pharmaceutical industry.

An important finding of the study is the identification of a direct relationship between the level of technological development and the economic efficiency of production. The implementation of modern agrotechnologies, automation, and digital management systems allows for cost reduction, increased yields, and stable product quality. In this context, Ukraine significantly lags behind EU countries, which necessitates technological modernization of the sector.

The analysis of economic indicators showed that the efficiency of medicinal plant cultivation is determined by a combination of factors, including cost structure, production cost level, labor productivity, the degree of product processing, and market conditions. It has been established that increasing the level of processing is one of the key reserves for enhancing added value and profitability.

The study also confirmed the important role of organic production as a promising direction for sector development. Despite higher costs and certification complexity, organic medicinal plant cultivation ensures higher profitability due to strong demand and premium prices in international markets.

Special attention was paid to the role of state support, which in EU countries acts as a key factor in ensuring stable sector development. The system of subsidies, grants, and development programs promotes innovation, improves product quality, and strengthens the competitive position of producers. In Ukraine, however, insufficient and fragmented state support remains one of the limiting factors in sector development.

It has been established that risk management is an essential element of effective sector functioning. Climatic, market, technological, and financial risks can significantly affect production outcomes; therefore, their minimization is a necessary condition for sustainable development.

Particular importance is attached to the development of processing infrastructure, cooperation among producers, scientific support, and integration into international markets. These factors determine the possibility of transitioning from a raw-material model to the production of high value-added products.

Based on the conducted research, it is substantiated that the strategic directions for the development of medicinal plant cultivation in Ukraine should include:

- technological modernization of production;
- development of product processing;
- implementation of international quality standards;
- support for organic production;
- strengthening of state support;
- integration into the European market.

Overall, the research results confirm that medicinal plant cultivation has significant potential as a promising sector of agriculture, capable of ensuring economic growth, rural development, and strengthening the country's position in the international market.

In summary, it should be emphasized that improving the efficiency of medicinal plant cultivation in Ukraine is possible only through a comprehensive combination of natural potential, modern technologies, effective state policy, and integration into the global economic system. This will ensure sustainable sector growth and increased competitiveness.

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