Kuzmych *et al. Discover Applied Sciences* (2026) 8:211
https://doi.org/10.1007/s42452-026-08221-z

Discover Applied Sciences

RESEARCH

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Experiences and prospects of Paisa management on the drained lands of the Ukrainian Polissia

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Abstract

The results of field studies conducted on drained lands in the humid zone of Ukrainian Polissia during the period 2016–2024 have determined the technological parameters of water management (groundwater levels and soil moisture in the root zone) for growing high-yielding forage crops of paisa on peat and mineral soils. Permissible terms have been established for the drainage system to ensure the removal of excess water and timely reduction of groundwater levels to recommended levels. It has been identified that modern climate changes in the Polissia Ecozone of Ukraine manifest in uneven distribution of precipitation during the growing season, anomalous fluctuations in average daily air temperature, and minimal nighttime air temperatures (< 10 °C) in the summer period, which impact agricultural production, especially the cultivation of heat-loving crops. Under such meteorological conditions, however, with optimal drainage regimes, the yield of paisa, a heat-loving crop by biological characteristics, was the lowest in 2019 compared to the period of 2016–2018, regardless of fertilization variants. It has been determined that in the conditions of climate change, characterized by exacerbated drought phenomena in the Polissia Ecozone of Ukraine, it is necessary to anticipate the accumulation of sufficient water volumes for irrigation of cultivated crops during dry periods of the growing season and to maintain optimal water management parameters on reclaimed lands by utilizing the water-retaining capacity of reclaimed territories and available surface water resources located outside drainage systems. Long-term trend analysis shows decreasing precipitation and rising air temperature, indicating climate stress conditions.

Article Highlights

- Long-term field studies (2016–2024) in the Polissia Ecozone of Ukraine established optimal water management parameters for cultivating paisa on drained peat and mineral soils.
- Climate change-induced anomalies—such as uneven rainfall and abnormal temperature fluctuations—significantly affect the yield of heat-loving crops like paisa.

- Optimal drainage regimes and fertilization strategies significantly influence vegetative mass, root development, and biomass productivity of paisa.
- Recommendations were developed for groundwater level control, irrigation scheduling, and agronomic practices to improve sustainability on reclaimed lands in humid zones.

Keywords Paisa (*Echinochloa frumentacea*), Drainage systems, Polissia, Water management, Climate change adaptation, Forage crops, Groundwater level, Soil moisture regulation

1 Introduction

Climate change significantly affects the direction of land use on drained lands, as it alters the agroclimatic conditions for growing agricultural crops. In the context of climate warming, agricultural lands in humid regions become particularly important. In Eastern Europe, including Ukraine and Poland, such a region is the Polissia, where extensive drainage measures and drainage systems have been implemented. Due to increasing anthropogenic pressure and climate change, the importance of rational use of these lands is growing [1–12].

Livestock farming remains a promising industry in the humid zone, particularly in Ukraine, which is impossible without a reliable feed base. Feed production is one of the main directions for the effective use of drained lands. One of the significant reserves for increasing productivity in modern conditions is the introduction of underutilized but highly productive crops capable of outperforming traditional crops in terms of yield, nutrient content, and climate resilience. Among these crops, multipurpose crops with high adaptive potential play an important role. Among such crops, paisa stands out, generating interest globally and in Ukraine, especially for its potential use on drained lands [13–22].

Paisa (*Echinóchloa frumentácea*) is the most productive high-energy forage crop, serving as feed for poultry and concentrated feed for pigs and cattle. In terms of nutritional value, it is not inferior to oats and barley, containing 93 kg of feed units, 10.5 kg of digestible protein, 5.0% fat, 10.0% fiber, 3.3% ash, 58.6% non-nitrogenous extractive substances, and 0.82% sugar per 100 kg. Paisa grain is rich in phosphorus and silicon, as well as zinc, copper, iodine, and bromine [23–27].

In 100 kg of green paisa mass at the flowering stage, there are 12.8 feed units and 1.5 kg of digestible protein. In 100 kg of paisa hay, there are 54 feed units and 10 kg of digestible protein, equivalent to 185 g of digestible protein per feed unit. Paisa contains the highest amount of digestible protein per feed unit compared to other cereal crops. Feeding dairy cows with paisa increases milk yield by an average of one and a half times [23].

The use of paisa grain for poultry feeding is of interest from both an economic and physiological-biochemical perspective. Whole paisa grain can be used in poultry rations without the need for additional energy costs for grinding, preserving the nutritional value of the grains by avoiding nutrient losses during grinding. Introducing whole paisa grain into the feed for laying hens during peak laying instead of 3–10% ground wheat grain increases egg productivity and egg weight. The highest productivity indicators were found in hens fed with feed containing 5% paisa grain. Poultry fed with this feed had 12.5% higher laying capacity and 2.5% higher egg weight [28].

Paisa ranks first among cereal crops in terms of mineral content. It silages well and produces a more nutritious and high-quality silage compared to traditional corn silage. The digestibility coefficient of protein is 44%, non-nitrogenous extractive substances – 71%, fiber – 59%, and fat – 60% [28].

Research conducted at the Polissia Institute of Agriculture of the National Academy of Agrarian Sciences of Ukraine showed that paisa outperformed other forage crops such as corn, soybean mixture, oilseed radish, amaranth, white mustard, and yellow lupine in terms of vegetative mass yield and feed unit collection on sod-podzolic soils. The application of mineral fertilizers increased paisa yield by 27%, and lime application by 11%. The maximum vegetative mass yield of paisa reached 30.4 t/ha, which was 17.2% higher than that of corn. Paisa also had a higher energy efficiency coefficient by 2.65.

Global experience in paisa cultivation demonstrates its significant potential in various agroclimatic conditions. In Asian countries such as China and India, paisa has long been used as a multipurpose crop due to its rapid growth, high productivity, and adaptability to various soil conditions. It is often grown in regions with insufficient moisture, where traditional forage crops do not provide stable yields [23, 28, 29].

In South American countries such as Brazil and Argentina, paisa is introduced as an alternative to traditional forage crops in mixed cropping systems. Its ability to accumulate green mass quickly makes it popular for use in no-till systems, contributing to soil conservation and fertility improvement [30–32].

In the USA, paisa is used as an intermediate forage crop and green manure, effectively enriching the soil with nitrogen and improving its structure. Due to these properties, it is included in sustainable agriculture programs aimed at enhancing the ecological resilience of agroecosystems [23, 33].

In Europe, particularly in Germany and France, paisa is gaining popularity as a forage crop in organic farming systems. Research in these countries has confirmed that paisa cultivation ensures high yields and improves the nutritional quality of feed. Its rapid vegetative growth is especially valued for multi-cut mowing systems [34, 35].

Belarusian scientists note that paisa can be grown on peat soils without waterlogging or lodging. The use of mineral fertilizers, especially nitrogen, in paisa cultivation for seeds and green mass can increase yields by up to 50% [36].

Since paisa is a moisture-loving crop, drained peatlands are favorable for its cultivation, where it can provide green mass yields of over 70 t/ha.In addition to the existing paisa varieties (Pauza, Perspektyva, Molodetska, Ussuriyska, Evrika), the "Nadia" variety (LLC "Vilna Ukraine") was created and zoned, recommended for cultivation in the Forest-Steppe and Polissia zones, and the "Lebedyna 2" variety (originator Institute of Agriculture Polissia NAAS), recommended for cultivation in the conditions of the Western Polissia zone [13].

On drained peat soils of the Sarny Research Station of the Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences of Ukraine, particularly in the drainage system "Chemerne," paisa yield exceeded 80 t/ha of vegetative mass. Research on a reclaimed peat bog showed that without the application of mineral fertilizers, the yield of vegetative mass of paisa variety "Lebedina 2" was 70.5 t/ha, and seed yield was 2.2 t/ha [37].

Therefore, among the breeding paisa varieties recommended for cultivation in the Western Polissia zone, the "Lebedina 2" variety deserves attention. In production conditions, its yield reaches 40–45 t/ha, with a raw protein content in green mass of 12.9%. This mid-ripening variety is resistant to lodging [38].

The conditions of the Ukrainian Polissia region create prospects for successful paisa cultivation. Its adaptability to local climatic and soil conditions, resistance to drought, and ability for multi-cut use make it a valuable resource for strengthening the feed base.

Research [39–41] shows that increasing paisa productivity on drained lands requires optimization of agronomic practices, including the justification of water management regimes.

The aim of the study is to scientifically substantiate technological parameters of water regime regulation for cultivating the high-yielding forage crop paisa on drained peat and mineral soils in the Polissia ecozone of Ukraine.

The integration of paisa into feed production on drained lands in the Polissia region will ensure stable yields, improve feed quality, and promote the development of sustainable agriculture in the face of climate change.

Thus, the development of feed production based on underutilized crops like paisa opens up opportunities for increasing the efficiency of drained lands in the Polissia region. This not only contributes to strengthening the feed base for livestock farming but also supports the sustainable development of the agricultural sector in the face of climate change and increasing anthropogenic pressure [23, 28].

2 Research methods and materials

Paisa (*Echinochloa frumentacea*) is a species of herbaceous plants belonging to the grass family (Poaceae).

The plants were collected in the Sarny District of Rivne Region, within the Western (Volyn) Polissia zone of Ukraine. The geographic coordinates of the collection site are 51°19′37″ N (north latitude) and 26°37′59″ E (east longitude).

The plant material was identified using the online service https://identify.plantnet.org/uk/k-world-flora/identify and [29].

The experimental design is based on standardized and widely accepted methodological approaches. These include continuous meteorological monitoring (air temperature, relative humidity, and precipitation), determination of soil moisture content, and assessment of key biometric indicators such as the timing of major phenological stages, leaf area index, root system development, and crop yield throughout the growing season [39–47].

An analysis of long-term climatic data covering the period from 1980 to 2024 indicates a persistent decrease in precipitation combined with a steady increase in air temperature, reflecting the formation of climate-related stress conditions for agricultural crops.

Soil moisture was determined using the thermostat–gravimetric method. Soil samples were collected at sub-decadal intervals from depths of 0–10, 10–20, 20–30, 30–40, and 40–50 cm in accordance with the requirements of DSTU ISO 11272:2001.

Field investigations of paisa water consumption were conducted based on the assessment of the principal factors governing crop water use, including meteorological conditions, groundwater table depth, and soil moisture reserves. In addition, the biological characteristics of the crop—such as ecological requirements, phenological development stages, and the duration of the vegetation period—were taken into account.

The key methodological principles for experimental research and the determination of paisa water consumption are founded on calculations of the water balance within the active (root) layer of the soil profile [45, 48]. The total water consumption for a given period was calculated using the following equation:

$$E = (W_{start} - W_{end}) + P_{eff} + q_1 - q_2, \tag{1}$$

where E - total water consumption for the given crop for the calculation period, mm; W_{start} and W_{end} - moisture reserves in the active soil layer at the beginning and end of the calculation period, mm; P_{eff} - amount of effective precipitation for the calculation period, mm; q_1 - amount of capillary feeding, mm; q_2 - amount of groundwater outflow, mm.

The results indicate that sowing method is the primary factor influencing both green biomass and grain yields of paisa, whereas sowing dates have no statistically significant effect on crop productivity. Depending on the intended use of paisa—either for green fodder or seed production—the selection of appropriate and efficient sowing techniques becomes particularly important. An evaluation of the nutritional characteristics of the green biomass and grain of the 'Nadia' paisa variety, as well as silage prepared from mixed green mass of paisa and leguminous species, confirms the high vegetative productivity of this crop [17, 18].

Paisa exhibits a broad sowing window and can be planted over a period of approximately 1–1.5 months, from early May to mid-June. This flexibility enables the extension of paisa utilization for various forage purposes. Harvesting of green biomass may begin at the early heading stage and continue until the milk–wax ripeness stage of the grain [20].

Sowing operations and crop management practices were conducted in accordance with standard cultivation technologies using machinery and equipment commonly employed under production conditions.

Prior to establishing the experiments, pre-sowing soil preparation was performed, including cultivation and harrowing. The accounting area of each experimental plot was 12 m^2, with three replications. Mineral fertilizers were applied once in spring at the following rates: $N_{45}P_{60}K_{120}$, $P_{60}K_{120}$, and $P_{60}K_{90}$.

Agrochemical and radiological analyses of soil and plant materials were conducted, and phenological monitoring of paisa growth and development was carried out. Because the experiments were performed on radioactively contaminated lands (with a ^{137}Cs contamination density of 48.5 kBq/m^2), spectrometric analyses were conducted to determine radiocesium content in paisa vegetative biomass.

Phenological observations of plant growth and development were conducted throughout the growing season in accordance with established methodologies for forage crops [29]. Yield assessment was performed using the whole-plot method across the entire accounting area [42].

Plant samples for radionuclide analysis were collected at ten points within each accounting plot, with individual sample weights ranging from 0.15 to 0.2 kg from a 1 m^2 area. The cutting height was maintained at 3–5 cm above the soil surface, following established guidelines [49]. The radionuclide content in soil and plant samples was determined by gamma spectrometry. Measurements of radiocesium activity were carried out in the station's radiological laboratory using a SEG-0.5 spectrometer equipped with a BDEG-63 K-01 scintillation detector, applying Marinelli geometry with a 1-L container and a counting time of 3600 s [49]– [50].

The research plots were established on the drained peat bog massif "Chemerne" of the Sarny Research Station of the Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences of Ukraine (Fig. 1).

The drainage and reclamation system of the peatland massif "Chemerne" comprises a water-receiving body, an extensive network of open channels (including main, collector, drainage, and catchment channels) equipped with hydraulic structures, as well as a closed regulating drainage network. The Sluch River serves as the water receiver and is located approximately 5 km from the drainage system [51–53].

The meliorative infrastructure includes a main first-order trunk canal and a secondary trunk canal, which discharges into the main canal in the eastern part of the massif. The main canals are positioned in the lowest relief zones of the peatland, where peat layers reach maximum thickness. Collector channels are arranged perpendicular to the main canals and have lengths ranging from 1 to 2 km. The spacing between collectors varies from 1 to 2 km, depending on surface slope conditions. Collectors are oriented parallel to the main canal, while catchment-drainage channels are designed to intercept both surface runoff and groundwater. In total, the system consists of 36 open channels, including two main canals. Subsurface drainage has been implemented over an area of 289 ha using tile, plastic, fiberglass, and fascine drains, with 327 collector outlets. The system also includes 49 hydraulic structures and one road bridge.

In the upper section of the massif, an accumulation reservoir has been created at the site of former peat extraction pits. The reservoir has a width of approximately 120 m, a length of about 1000 m, and a depth of 1.0–1.25 m, providing a potential water storage capacity of approximately 385,000 m^3.

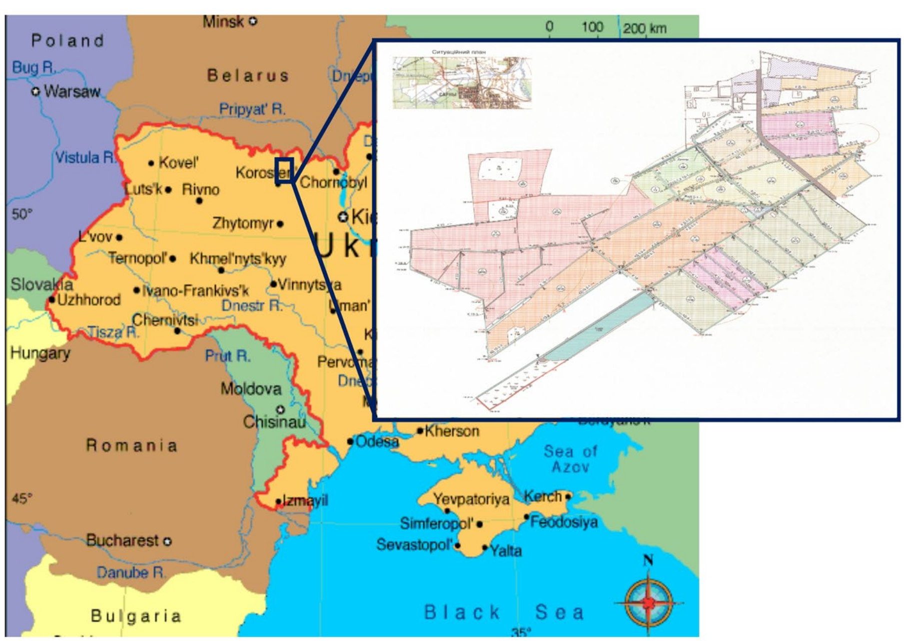

Fig. 1 Scheme of the drained peat bog massif "Chemerne" of the Sarny Research Station of the Institute of Water Problems and Land Reclamation of the National Academy of Agrarian Sciences of Ukraine (Polissia Ecoregion, Rivne region, Ukraine)

During periods of intense precipitation, groundwater levels rise to depths of 0.1–0.3 m over 10–25% of the territory. As a result, the initiation of field operations is delayed by 11–12 days, and in certain years by up to 14–16 days. The total area affected by waterlogging accounts for 23.7% of the agricultural land.

The experimental site within the "Chemerne" peatland massif is equipped with two sets of tensiometers for monitoring soil moisture within the root zone, as well as a water-regulating device designed to maintain optimal soil water conditions.

The soils of the experimental plots are classified as lowland peat soils with a high organic matter content and substantial peat thickness, supplied by groundwater inflow from adjacent mineral soils, predominantly sod-podzolic in origin. The dominant peat-forming vegetation includes sedge–paisa–reed communities, while the lower peat horizons frequently contain partially decomposed remains of woody species such as willow, birch, alder, and pine, as well as white moss. Peat thickness varies from 1 to 4 m, decreasing toward the margins of the massif to 0.3–0.5 m, where peat-gley soils with elevated ash content are formed.

The peat soils of the research area are well decomposed. The peat matrix primarily consists of residues of sedge grasses, reeds, and hypnum mosses. Paisa had not been previously cultivated on the site. The peat layer reaches depths exceeding 2 m.

Based on ash content classification, the peat soils of the experimental plots are categorized as medium-ash, with ash content ranging from 16 to 18%.

Agrochemical analysis indicates that the soil reaction is slightly acidic (pH_sol 5.0–5.2). The soils are well supplied with nitrogen, moderately supplied with phosphorus, and poorly supplied with potassium. The availability of mobile nutrient forms is as follows: nitrogen (N) – 65.5 mg/100 g, phosphorus (P_2O_5) – 18 mg/100 g, and potassium (K_2O) – 13 mg/100 g of soil.

3 Results and discussion

The territory of the peat bog massif "Chemerne" is located in the Northern agroclimatic region in the zone of Western Polissia of Ukraine (northern part of Rivne region) (Fig. 1).

According to the agrosoil zoning scheme, the study area is classified within the Stepansky agrosoil district of the Polissia province, belonging to the western subzone of chernozem–podzolic soils. Hydrogeological investigations indicate that the research site is situated within the Polissia sandy plain, which occupies the central and northern parts of Rivne Region. The Polissia lowland, encompassing a substantial portion of Rivne Region, represents a gently undulating plain with elevations ranging from 150 to 210 m above sea level. A defining characteristic of this landscape is the high degree of waterlogging and the widespread presence of peat layers over sandy and loamy substrates. Wetlands occur both within river floodplains and in interfluve areas.

From a geostructural perspective, the reclaimed lands of the experimental site are located in the eastern part of the Volyn Upland, which is distinguished by a well-developed microrelief. Quaternary deposits in this area are represented by a diverse assemblage of sedimentary complexes that contribute to the distinctive relief of the territory [38, 50, 54–57].

Within the boundaries of the study area, Quaternary alluvial deposits associated with the floodplain of the Horyn River are widely developed and are predominantly composed of light-gray, fine- to medium-grained quartz sands. In certain boreholes, sandy layers extend to depths of up to 7.5 m. These sands are overlain by modern lacustrine–marsh deposits consisting of dark-brown, well-decomposed peat and chernozem–carbonate soils. The thickness of peat layers varies considerably, ranging from 0.5 to 6.5 m. Groundwater levels were recorded at depths between 0.65 and 1.9 m below the surface.

Based on the genetic characteristics of the water-bearing strata, the groundwater belongs to aquifers associated with alluvial floodplain deposits and contemporary lacustrine–marsh sediments. Groundwater within alluvial deposits is distributed along narrow belts following the Horyn and Sluch rivers and their numerous tributaries and occurs within fine- and medium-grained sandy layers. Floodplain groundwater typically lies at depths of 3–4 m and represents the uppermost aquifer, which is hydraulically connected both to the river system and to deeper aquifer horizons developed in pre-Quaternary formations.

The aquifer associated with lacustrine–marsh deposits is characterized by shallow groundwater occurrence, ranging from 0.1 to 1.3 m below the surface, and is confined to peat and silty sediments. This groundwater horizon is primarily recharged by atmospheric precipitation and by inflow from underlying aquifers, with which it commonly maintains hydraulic connectivity. During the spring period, groundwater levels rise to the surface and, in combination with surface runoff, lead to the formation of marshy conditions. The groundwater is of hydrocarbonate–calcium type, with pH values ranging from 7.1 to 7.5 [39, 41, 49, 51].

Granulometric composition of soils was determined using the pipette method (Kachinsky, 1965), which allows for the quantitative separation of soil particles by size fractions. The analysis was carried out on samples collected from different genetic horizons of the studied soils. Particle-size fractions were classified into gravel (> 1.00 mm), coarse and medium sand (1.00–0.25 mm), fine sand (0.25–0.05 mm), silt (0.05–0.001 mm), and clay (< 0.001 mm). The results of the granulometric analysis are presented in Table 1.

In terms of climate. Western Polissia differs from other regions of Polissia located in the east with milder winters. warmer summers. and higher precipitation (from 600 to 700 mm per year). The heterogeneity of this region in both climatic and geomorphological aspects determines the different degree of marshiness and the uneven character of bogs.

Spring begins in the second decade of March and lasts for 70–80 days. Its characteristic feature is the rapid rise in temperature. In the first decade of April. the average daily temperatures do not exceed 5 °C. and in the third decade. they reach 10 °C. which

Table 1 Granulometric composition of soils in the peat bog Massif "Chemerne", Rivne region

Soil type	Layer, m	Fraction size, mm				
		Gravel	Sand	Silt	Clay	
		1.00-0.25	0.25 – 0.05	0.05 – 0.01	0.01 – 0.005	0.005 – 0.001
Derno-carbonate	0–20	–	24.0	55.1	4.3	16.6
	0.20–0.50	–	27.6	53.4	3.3	15.7
	0.50–0.90	–	66.0	20.3	2.7	11.0
	0.9–1.2	12.3	71.6	10.7	0.5	4.9
Peat-gley	0–0.2	1.40	22.89	58.64	7.75	2.9
	0.2–0.5	2.24	17.36	61.03	5.69	8.64
	0.5–0.9	1.56	17.87	60.80	3.94	5.24
	0.9–1.2	1.20	18.47	56.16	3.59	3.35

promotes the intensive growth of most crops. In spring. there are often frosts that damage orchard and garden crops.

Summer is mainly warm. with sufficient moisture. It starts in the third decade of May when the average daily air temperature exceeds 15 °C and lasts until early September. In the hottest month. July. the average air temperature ranges from 17 °C to 19 °C. with maximum temperatures from 36 °C to 38 °C. Summer showers with thunderstorms and sometimes hail occur. Due to heavy rains. grain crops can lodge. and the topsoil can be washed away. In some years. there may be drought in summer.

Autumn begins at the end of September or early October when the average daily temperature drops below 10 °C. Between the end of summer and the beginning of autumn. there is a pre-autumn period - the month of September when the average daily air temperature exceeds 10 °C. September is characterized by mostly clear dry weather. The vegetation period ends in late October when the average daily air temperature drops below 5 °C.

According to the research methodology. meteorological observations were conducted to determine atmospheric precipitation and air temperature on the meliorative system of the peat bog massif "Chemerne" the results of which are presented in Tables 2 and 3. Long-term trend analysis shows decreasing precipitation and rising air temperature, indicating climate stress conditions.

According to the methodology, research was conducted to establish the optimal sowing dates that ensure the highest level of productivity realization of paisa. The results of the research during 2016–2024 indicate that the speed of seedling emergence of paisa is influenced by atmospheric precipitation, soil moisture, and temperature. For the biometric characteristics of paisa, we took the year 2020 as a base, as it is an average-dry year according to our research on the average annual precipitation supply from 1980 to 2024.

Table 2 Atmospheric precipitation and their deviations from the average multi-year indicators, vegetation period 2016–2024, meliorative system of the peat bog Massif "Chemerne"

Indicators	Month						Sum IV-IX
	IV	V	VI	VII	VIII	IX	
Average multi-year norm, mm	45.0	59.0	94.0	81.0	63.0	58.0	400.0
Precipitation in 2016, mm	31.0	32.8	13.5	64.5	25.5	8.3	175.6
Deviation of precipitation from the norm, mm	−14.0	−26.2	−80.5	−16.5	−37.5	−49.7	−224.4
Precipitation in 2017, mm	19.1	40.4	39.2	53.9	22.4	52.0	227.0
Deviation of precipitation from the norm, mm	−25.9	−18.6	−54.8	−27.4	−40.6	−6.0	−173.0
Precipitation in 2018, mm	11.7	37.9	35.8	54.2	98.0	17.4	255.0
Deviation of precipitation from the norm, mm	−33.3	−21.1	−58.2	−26.8	+35.0	−40.6	−145.0
Precipitation in 2019, mm	36.1	125.8	26.9	88.5	35.6	4.3	317.2
Deviation of precipitation from the norm, mm	−8.9	+66.8	−67.1	+7.5	−27.4	−53.7	−82.8
Precipitation in 2020, mm	3.6	78.4	106.6	83.3	53.5	9.3	334.7
Deviation of precipitation from the norm, mm	−41.4	+19.4	+12.6	+2.3	−9.8	−48.7	−65.3
Precipitation in 2021, mm	35.3	71.1	34.8	57.6	61.6	49.1	309.5
Deviation of precipitation from the norm, mm	−9.7	+12.0	−59.2	−23.4	−1.4	−8.9	−90.5
Precipitation in 2022, mm	33.8	22.6	36.6	52.1	26.3	72.9	244.3
Deviation of precipitation from the norm, mm	−11.2	−48.5	−57.4	−28.9	−36.7	+14.9	−155.7
Precipitation in 2023, mm	39.9	9.1	55.9	66.3	52.4	9.7	233.3
Deviation of precipitation from the norm, mm	−5.1	−49.9	−38.1	−14.7	−10.6	−48.3	−166.7
Precipitation in 2024, mm	29.7	34.3	62.0	133.8	12.7	31.5	304.0
Deviation of precipitation from the norm, mm	−15.3	−24.7	−32.0	+52.8	−50.3	−26.5	−96.0

Table 3 Average monthly air temperature and its deviations from the average multi-year indicators, vegetation period 2016–2024, meliorative system of the peat bog Massif "Chemerne"

Indicators	Month						Sum IV-IX
	IV	V	VI	VII	VIII	IX	
Average multi-year norm, °C	8.0	14.1	17.0	18.2	17.4	13.1	14.6
Average monthly temperature in 2016, °C	9.2	14.9	19.5	20.7	18.8	13.8	16.2
Deviation from the norm, °C	+1.2	+0.8	+2.5	+2.5	+1.4	+0.7	+1.7
Average monthly temperature in 2017, °C	7.8	13.9	18.6	19.2	19.9	13.4	15.5
Deviation from the norm, °C	−0.2	−0.2	+1.6	+1.0	+2.5	+0.3	+0.9
Average monthly temperature in 2018, °C	12.7	17.6	18.8	19.9	19.3	14.7	17.1
Deviation from the norm, °C	+4.7	+3.5	+1.8	+1.7	+1.9	+1.6	+2.5
Average monthly temperature in 2019, °C	8.8	14.3	22.2	18.4	18.6	12.7	15.8
Deviation from the norm, °C	+0.8	+0.2	+5.2	+0.2	+1.2	−0.4	+1.2
Average monthly temperature in 2020, °C	7.4	10.9	20.4	19.1	19.4	15.4	15.4
Deviation from the norm, °C	−0.6	−3.2	+3.4	+0.9	+2.0	+2.3	+0.8
Average monthly temperature in 2021, °C	6.2	13.2	20.7	23.3	17.6	11.2	15.4
Deviation from the norm, °C	−1.8	+0.9	+3.7	+5.1	+0.2	−1.9	+0.8
Average monthly temperature in 2022, °C	8.3	12.7	20.2	19.4	20.0	10.3	15.2
Deviation from the norm, °C	+0.3	−1.4	+3.2	+1.2	+2.6	−2.8	+0.6
Average monthly temperature in 2023, °C	7.4	14.1	17.1	19.9	21.0	16.4	16.0
Deviation from the norm, °C	−0.6	0.0	+0.1	+1.7	+3.6	+3.3	+8.1
Average monthly temperature in 2024, °C	9.5	15.8	19.9	22.1	21.5	17.6	17.7
Deviation from the norm, °C	+1.5	+1.7	+2.9	+3.9	+4.1	+4.5	+3.1

Table 4 Dates of the onset of the main growth phases of paisa, peat bog Massif "Chemerne"

Crop	Sowing	Germination		Appearance of true leaf (seedling)	Budding tillering	Flowering		Seed ripening	
		Appearance	Complete			Beginning	Full	Beginning	Full
Paisa	06.05	10.05	15.05	18.05	21.07	10.08	14.08	26.08	05.09

Table 5 Dynamics of linear growth of paisa, cm; peat bog "Chemerne"

Fertilization system	Date of plant height measurement									
	30.05	10.06	20.06	30.06	10.07	20.07	30.07	10.08	20.08	30.08
$P_{60}K_{90}$	3	8	22	31	60	84	99	126	134	165
$P_{60}K_{120}$	3	9	23	35	63	95	110	139	145	171
$N_{45}P_{60}K_{120}$	4	10	27	39	72	101	114	147	157	178

The onset of the main growth phases of paisa in 2020 in the experimental plot of the peat bog massif "Chemerne" is shown in Table 4.

As the research showed, paisa grows and develops relatively slowly at the beginning of the vegetation period (May-early June). During this period, it requires protection from weeds, as weeds develop intensively on peat soils and can suppress cultivated crops. The most intensive linear growth of vegetative mass of paisa occurs during the period from June 30 to August 20 (Table 5). In the conditions of the vegetation period of 2020, paisa reached a height of 168 cm.

The indicators of leaf surface formation of paisa during the vegetation period in 2020 are presented in Table 6. The results obtained indicate that paisa has different indicators of leaf surface growth.

The leaf surface of paisa at its maximum during the period depending on the fertilization variant was 93.7-101.7 thousand m^2/ha. Paisa was characterized by slow formation

Table 6 Dynamics of leaf surface formation of Paisa during the vegetation period, thousand m^2/ha; peat bog "Chemerne"

Fertilization	Dates of measurement								
	20.05	30.05	10.06	20.06	30.06	10.07	20.07	30.07	10.08
$P_{60}K_{90}$	–	0.5	8.6	28.1	38.9	67.4	76.5	92.9	0.5
$P_{60}K_{120}$	–	0.5	9.2	29.7	40.9	70.9	80.4	97.8	0.5
$N_{45}P_{60}K_{120}$	–	0.5	9.3	30.6	42.1	72.8	82.7	100.5	0.5

Table 7 Depth of penetration of the Paisa root system depending on fertilization (average for 2016–2024), cm; peat bog "Chemerne"

Fertilization	Development phase					
	3rd leaf	stage of bushing	emergence of tendrils	heading	milky-waxy ripeness of seeds	full seed ripeness
$P_{90}K_{90}$	5	12	31	45	52	57
$P_{60}K_{120}$	6	14	34	47	54	60
$N_{45}P_{60}K_{120}$	7	15	35	48	56	62

Table 8 Accumulation of organic residues by forage crops depending on fertilization (t/ha of dry matter), peat bog "Chemerne"

Crop	Fertilization	Root system mass, t/ha
Paisa	$P_{90}K_{90}$	4.62
	$P_{60}K_{120}$	4.78
	$N_{45}P_{60}K_{120}$	5.16

of leaf surface up to 28–30 days after emergence, after which a more rapid increase occurred. The maximum indicators of assimilation surface of paisa were noted on the 80-90th day after emergence. The most intensive increase in leaf surface of paisa was observed during the period from June 20 to July 20 (Table 6).

After 80–90 days, the flowering and seed ripening phases occur, during which the growth of the assimilation surface of the paisa stops. Therefore, on 10.06 this indicator is 0.5 thousand m^2/ha (Table 6).

The results of the study on the depth of penetration of the root system into the soil during the phases of paisa development depending on fertilization are presented in Tables 7, 8 and 9.

The root system of paisa is fibrous, sufficiently powerful, and penetrates to a depth of up to 62 cm (Table 7), with the main mass of roots concentrated in the plow layer of soil (0–30 cm).

The results of the study [23, 28] on the accumulation of organic residues of the paisa root system are presented in Table 8.

The accumulation of organic residues of the root system during the growing season when cultivating paisa depending on fertilization ranges from 4.62 to 5.16 t/ha. This is explained by the presence of a sufficiently powerful root system in this crop.

When sown on April 15 and with a soil temperature of 0–10 cm depth at 12.4 °C, the "sowing-emergence" phase in paisa lasts for 15 days. When sowing on April 30 and May 15 at soil temperatures ranging from 14.1 to 19.9 °C, paisa seedlings emerge on the 8th-9th day (Table 9).

Table 9 Influence of agroclimatic indicators on the duration of the "sowing-emergence" phase in Paisa cultivation

Sowing date	Agroclimatic indicators from sowing to emergence			Duration of "sowing-emergence" phase, days
	Average daily air temperature, °C	Soil temperature at 0–10 cm depth, °C	Precipitation, mm	
April 15	11.3	12.4	8.2	18
April 30	12.1	14.1	18.6	12
May 15	18.5	19.9	21.0	10

For seed swelling and germination, the moisture content of the sowing layer of the soil, provided by 30–40 mm of precipitation, is important [7]. The seed imbibition capacity of paisa seeds ranges from 174 to 260% [15]. Field research results indicate a close relationship between field emergence and sowing dates (Table 10).

Based on the field emergence rate of 62.4% the late sowing date at a soil temperature of 19.9 °C is preferred. With soil temperature fluctuations in the range of 12.4–14.1 °C observed during the period from April 15–30. the field emergence was lower at 30.7–46.9%.

To achieve high yields of green biomass from productive forage crops, it is essential to establish stands with an optimal leaf area that remains photosynthetically active for an extended period. The influence of sowing dates of paisa legumes on aboveground biomass formation was determined. Showing that the most favorable conditions for aboveground biomass formation occur when sown on May 15. At all stages of development there is an accumulation of 8.1–16.7% more green mass and 2.1–9.6% dry matter. The highest accumulation of vegetative mass (3.3 kg) is noted during the flowering phase and dry matter (680 g/m^2) during the milk-wax ripeness period (Table 11).

To conduct research on determining the optimal parameters of water regulation in the reclamation system of the peat bog massif "Chemerne," liming was carried out at a rate of 5 t/ha of CaCO3 to neutralize the increased soil acidity. The calculated rates of mineral fertilizers were applied.

According to the research results, during the growing season, the moisture requirements of paisa in the root layer of the soil vary depending on their biological needs and current meteorological conditions. Critical periods for overmoistening are spring floods and summer-autumn floods, typical for the humid zone. In the spring period, timely reduction of the GWL (Groundwater level) to a level that allows the passage of agricultural machinery, pre-sowing soil preparation, and crop sowing is a necessary requirement.

For the cultivation of paisa, permissible deadlines for the reclamation system to remove excess water are established (Table 12).

Recommended GWL and soil moisture norms in the root layer of the soil during the growing season for the cultivation of paisa are also established.

The main technological parameters for the cultivation of paisa, including by development phases of the crop and taking into account the critical periods of its optimal moisture supply, optimal irrigation regimes (drainage), agronomic practices, and optimal fertilization rates for peat soils are provided in Table 13. For drained soils (both mineral and peat), average moisture in the 0–30 cm layer at sowing is 75–80% of field capacity (FC). Recommended soil moisture during active vegetation: peat soils 65–75% (min 55–60% in summer); mineral soils 65–80% (min 55–60%).

The greatest decrease in paisa yield was observed in 2019 due to meteorological conditions, which manifested in uneven distribution of precipitation, spikes in average monthly temperature (in June and August, its values exceeded the average long-term norm by 5.2 °C and 1.2 °C respectively), and abnormally low night temperatures (< 10 °C) in July and August. Under such meteorological conditions, but with optimal meliorative regimes, the yield of paisa, which is a heat-loving crop by biological characteristics, was the lowest in all fertilization options compared to the average during the period 2016–2024.

Table 10 Average stand density of Paisa depending on sowing date (plants/m^2)

Sowing date	Number of plants		Field emergence, %	Plant survival coefficient
	At emergence	At harvest		
April 15	46	37	30.7	0.80
April 30	70	54	46.9	0.77
May 15	94	74	62.4	0.79

Table 11 Influence of sowing date on aboveground biomass accumulation in Paisa

Sowing date	Development stage					
	budding		flowering		full ripeness	
	Linear growth of plants, cm/day	Daily growth, g/m^2	Linear growth of plants,, cm/day	Daily growth, g/m^2	Linear growth of plants,, cm/day	Daily growth, g/m^2
April 15	*1.1*	*177*	*2.8*	*605*	*1.8*	*654*
April 30	*1.3*	*198*	*3.1*	*649*	*1.9*	*668*
May 15	*1.4*	*205*	*3.3*	*660*	*2.0*	*680*

Table 12 Deadlines for excess water removal when growing paisa, days

Crop	From the soil surface	From the soil layer 0–0.25 m	From the soil layer 0–0.50 m
Paisa	1–2	2–4	5–6

Since the research was conducted on radioactively contaminated lands (137Cs contamination density is 48.5 kBq/m^2) of the peat bog "Chemerne," a spectrometric analysis of plant samples was also conducted to determine the content of radiocesium in the vegetative mass of paisa. Therefore, on drained peat soils with contamination density of radionuclides up to 1 Ci/km^2, the vegetative mass of paisa in terms of radionuclide contamination during the research years was within permissible levels and met sanitary-hygienic standards, thus it can be used for animal feeding without restrictions.

Plant producibility of paisa is governed not only by biomass and grain yields but also by plant reproducibility, which encompasses stable seed formation, high field emergence, and effective vegetative regeneration after mowing. A well-developed root system and optimized groundwater and soil moisture regimes ensure sustained stand renewal and productivity under variable hydrothermal and climate-stress conditions.

4 Future research directions

Future research should focus on developing climate-resilient paisa varieties to withstand temperature fluctuations, drought, and excessive moisture in the Polissia Ecozone. Integrated water and nutrient management models are needed for optimal groundwater level regulation and irrigation planning on reclaimed lands. Monitoring soil health indicators like carbon content, nutrient balance, and microbial activity under different drainage and fertilization practices will provide insights into paisa cultivation sustainability. Scaling up agroecological practices by integrating paisa into crop rotations can enhance biodiversity, reduce chemical inputs, and improve system resilience. Peat grown on drained peat soils with a radionuclide contamination density of up to 1 Ci/km^2 can be used without restrictions for animal feeding. Socioeconomic studies are crucial to assess cost-effectiveness, farmer adoption, and policy support for wider application of underutilized crops like paisa in climate-smart agriculture.

Table 13 Main technological parameters for the cultivation of Paisa

Vegetation phase						
		Seedling-bush formation	**Exit to the tube**	**Ear emergence**	**Flowering**	**Seed ripening**
Duration from the beginning of vegetation (phase)		7	52(45)	80(28)	98(18)	131(33)
Periods of optimal moisture supply		2nd decade of June – 3rd decade of July				
Recommended GWL, cm (in the numerator - optimal; in the denominator - the minimum permissible in the summer period)	Peat soils	0,60 – 0,65 0,65 – 0,70	0,60 – 0,75 0,75 – 0,85	0,60 – 0,75 0,75 – 0,85	0,75 – 0,85 0,90 – 0,95	0,75 – 0,90 0,9 – 1,0
Optimal moisture content, % of field capacity	Peat soils	70–75	65–80	75–80	70–85	70–85
Fertilization rate		On drained peat soils – N60P120 (applied once during the main tillage)				
Agronomic practice		Inter-row cultivation	Inter-row cultivation			

5 Conclusions

It was established that when growing paisa on drained lands, it is necessary to adhere to sowing deadlines considering their intended use (green mass, grain), as excessively early sowing dates lead to intensive weed growth and a high probability of damage from spring frosts, while late sowing can result in drying of the topsoil, which is unacceptable during the "germination and emergence of seedlings" phase.

Based on the research results of 2016–2024, the main technological parameters of paisa cultivation were determined, including development phases and critical periods of optimal moisture supply, agronomic practices, and optimal fertilization rates when growing on peat and mineral soils. Permissible terms were established for the meliorative system to ensure drainage of excess water and timely reduction of groundwater levels to recommended values.

It was found that modern climate changes in the humid zone of Ukraine (uneven distribution of precipitation during the growing season, abnormal spikes in average monthly air temperature, and low night temperatures (< 10 °C) in summer months) affect the cultivation of heat-loving crops, including paisa. In the conditions of climate change, for irrigation measures on reclaimed lands, it is necessary to anticipate the accumulation of necessary water volumes in storage tanks or reservoirs for irrigation of cultivated crops during dry periods of vegetation and to ensure optimal water regulation parameters. Long-term trend analysis shows decreasing precipitation and rising air temperature, indicating climate stress conditions.

On radioactively contaminated reclaimed lands of the peat bog "Chemerne," the vegetative mass of paisa in terms of radionuclide contamination during the research years was within permissible levels, thus it can be used for animal feeding without restrictions.

Author contributions
L.K. and H.V. wrote the main manuscript text, M.Z. and M.S. prepared Tables 1, 2, 3 and 4, W.H. wrote the conclusions, S.K. and D.S. prepared Tables 5, 6, 7, 8, 9, 10, 11 and 12.

Funding
This work received no funding.

Data availability
All data generated or analysed during this study are included in this published article [and its supplementary information files].

Declarations

Ethics approval and consent to participate
This work does not involve any participants and as such ethical approval was not sought.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 28 March 2025 / Accepted: 1 January 2026
Published online: 10 January 2026

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