

Systematic Review

Cowpea (*Vigna unguiculata* (L.) Walp.): A Sustainable Crop for the Utilization of Sandy Soils Under Climate Change Conditions in Romania—A Systematic Review

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Abstract

The study on the valorization of natural resources through cowpea cultivation represents a challenge to mitigate the negative effects of climate change on the environment and on the food security of the population in drought-affected areas globally, and specifically in the sandy soil area of Romania. Thus, the existence in Romania of an area of approximately 439,000 ha with sands and sandy soils, soils with low natural fertility (below 1.2% humus) and with deficient hydrophysical properties, implies finding solutions for their efficient valorization through ecological modeling of the species/varieties structure, depending on the adaptability of the plant in a given area. In this sense, given the economic importance of cowpea, given by the plant's properties (drought resistance, source of increasing the organic matter content in sands, source of atmospheric nitrogen fixation, good precursor plant, source of protein for humans and animals), the cultivation of this species in a sustainable agricultural system is outlined, as an alternative solution to the cultivation of other leguminous plants. Considered a crop suitable for a climate change scenario, the conservation of genetic biodiversity and the establishment of technological inputs are essential objectives for promoting cowpea in a sustainable agricultural system, given the increasing drought in the world and the increasing need for protein.

Keywords: abiotic stress; drought tolerance; genetic resources; grain legumes; irrigation management; nitrogen fixation; plant breeding; soil fertility; sustainable agriculture; water-use efficiency

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1. Introduction

The projected growth of the global population, the continuous decline in arable land, and the increasing impact of climate change require urgent measures to ensure global food security. The valorisation of natural resources in sandy soil areas through

cowpea cultivation offers a sustainable response to the growing challenges posed by climate change and food insecurity, particularly in drought-prone regions. These studies are driven by the need to identify resilient agricultural systems capable of maintaining productivity under increasingly adverse environmental conditions. Their importance is underscored by several global trends. The world's population is projected to reach approximately 10 billion by 2050, significantly increasing the demand for food. At the same time, the extent and quality of arable land are declining due to land degradation, while climate change is intensifying the frequency and severity of droughts and other extreme weather events. Together, these pressures place unprecedented strain on agricultural systems and highlight the urgent need for climate-resilient crops and sustainable land management practices. In this context, promoting cowpea cultivation in sandy soils represents a promising strategy to improve the productive use of marginal lands, enhance agricultural resilience, and contribute to long-term food security [1,2]. Recent studies have identified climate change and climate variability as major threats to global food and nutritional security, significantly reducing crop productivity, particularly in tropical and subtropical regions [3–6]. As a drought-tolerant legume, cowpea is widely cultivated by smallholder farmers throughout sub-Saharan Africa and other warm and hot regions with limited rainfall [7]. Furthermore, projections indicate that by 2100, the continued increase in greenhouse gas emissions will raise the global mean temperature by approximately 2 °C, resulting in substantial economic losses worldwide. Agricultural production will be affected not only directly through changes in agroclimatic conditions but also indirectly through alterations in soil properties and shifts in the occurrence and distribution of pests and diseases [8].

Under these circumstances, this study focuses on the cowpea crop (*Vigna unguiculata* L. Walp), synthesising regional research in South-Eastern Europe, and more specifically in Romania. We tried to identify studies addressing a wide variety of topics: the overall importance of the plant, the progress achieved through genetic improvement and the roles of certain abiotic factors in the plant's growth and development.

Numerous studies worldwide have demonstrated that cowpea performs well on low-productivity sandy soils owing to its high tolerance to heat and water stress [9–12]. Consequently, the development of sustainable agricultural systems in these marginal environments requires selecting species and cultivars with high adaptability to adverse climatic and soil conditions, as well as implementing appropriate management practices to ensure long-term sustainability and food security in drought-prone regions [13–15].

In Romania, research has identified the sandy soils of southern Oltenia as one of the regions most vulnerable to desertification due to increasing air temperatures and the progressive intensification of soil water deficits [16,17]. Addressing these challenges requires sustainable strategies for the agricultural use of these fragile soils, including the introduction of crop species that can tolerate combined heat and drought stress. Cowpea represents one of the most suitable alternatives because of its remarkable adaptability and its multiple agronomic and environmental benefits [18,19]. Expanding research on cowpea cultivation in Romania has therefore become increasingly important, particularly to improve agricultural productivity on inherently low-fertility soils, where the cultivation of other grain legumes, such as common bean and soybean, is often constrained by numerous environmental limitations [20].

This review examines the potential of cowpea cultivation on sandy soils in Romania as an adaptation strategy to increasing drought under climate change. It synthesises national and international research on the crop's key biological and agronomic attributes, including drought tolerance, biological nitrogen fixation, nutritional value, and cultivation practices. Particular emphasis is placed on technological aspects such as genotype

selection, fertilisation, sowing, water management, and the control of weeds, pests, and diseases, providing practical guidance for farmers. The literature review is based on relevant studies published in Romanian and English that address cowpea cultivation, drought, and climate change.

2. General Context of the Review

2.1. Origin and Geographic Distribution

Cowpea (*Vigna unguiculata* (L.) Walp.), native to Africa, is an annual diploid ($2n = 22$), herbaceous species belonging to the family Fabaceae and is predominantly self-pollinated (approximately 95%) [21]. It is one of the most important food and forage legumes cultivated in semi-arid tropical regions, including parts of Africa, Asia, Southern Europe, the southern United States, and Central and South America, where it serves as a major source of plant protein, carbohydrates, vitamins, and minerals for millions of people [22–27].

Cowpea is cultivated for grain, green biomass, and forage, particularly in tropical and subtropical regions, where it plays a crucial role in food security and human nutrition in developing countries [21,28]. In sub-Saharan Africa and in some other regions of Asia and South America, cowpea plays an important role in traditional agricultural systems, contributing significantly to household food security and generating income for millions of small farmers, as well as for traders who sell these seeds with a rich nutritional value [29–31].

According to FAO statistics [32], although the harvested area in Europe is quite small, the yield is much higher than on all other continents. Thus, in 2024, only 6933 ha were used for cowpea, all in Southern Europe, but the average yield obtained was 3400.5 kg ha^{−1} (Table 1). Considering its much higher productivity and other advantages, expanding the harvested area for cowpea in Europe could be a “winning” option for European agriculture in the coming decades.

Table 1. Area harvested and yield for cowpea by continents for 2024 (FAO, 2026).

Continent	Area Harvested (ha)	Yield (kg ha ^{−1})	Description
Africa	15,525,671	630.3	Estimated value
North America	9270	1109.8	Official value
South America	13,127	1475.5	Official value
Asia	187,705	1240.8	Estimated value
Europe	6933	3400.5	Estimated value
Australia and New Zealand	-	-	Missing value; data cannot exist

2.2. Drought Adaptation and Climate Resilience

Climate change analysis based on historical data and projections indicates more frequent, intense, and prolonged drought events, with a concerning increase in the area affected by desertification, especially in Southern Romania, thereby threatening the sustainability of future agricultural production [33–35]. Owing to its biological and morphological characteristics, including a deep root system, a waxy leaf surface, and efficient mechanisms to prevent excessive water loss through stomatal closure, cowpea is well adapted to drought conditions and exhibits high water-use efficiency under water-limited environments [7].

Although cowpea is recognised as a drought-tolerant crop, recent evidence indi-

cates that soil water deficit during the early stages of vegetative growth can significantly impair plant growth and development, ultimately reducing productivity. Consequently, conserving genetic diversity and optimising crop management practices have become key priorities for promoting cowpea cultivation within sustainable agricultural systems, particularly amid increasing drought frequency and growing global demand for plant-based protein [36–38].

Experimental studies involving three cowpea genotypes subjected to drought stress revealed that morphophysiological traits were more severely affected after 14 days of stress than after 28 days. This pattern suggests that cowpea can partially acclimate to prolonged drought by activating adaptive physiological mechanisms that mitigate stress effects over time [29]. This adaptive potential, together with its ability to fix atmospheric nitrogen, makes cowpea a particularly valuable crop for cultivation in semi-arid regions, where agricultural productivity largely depends on soil moisture availability [39].

Excess soil moisture is also detrimental to cowpea growth and development, and it is particularly susceptible to flooding stress during the reproductive stage, resulting in reduced pod formation and lower grain yield [40,41].

2.3. Nutritional Value and Quality Attributes

Cowpea is widely recognised as a highly nutritious crop, providing an excellent source of proteins, dietary fibre, vitamins, minerals, antioxidants, trace elements, and other bioactive compounds that contribute to human health [42–44]. Its seeds typically contain 23–32% protein, 50–60% carbohydrates, and only 1–2% fat, making them comparable in nutritional value to other major grain legumes such as common bean (*Phaseolus vulgaris*), chickpea (*Cicer arietinum*), lentil (*Lens culinaris*), and pea (*Pisum sativum*) [31,45]. In addition to the seeds, cowpea leaves and immature green pods are rich in proteins, carbohydrates, vitamins, dietary fibre, and minerals. Leaves harvested from two weeks after emergence until flowering are particularly valuable due to their high concentrations of β -carotene and iron, ranging from 0.25–36.55 mg/100 g dry matter and 0.17–75.00 mg/100 g dry matter, respectively [46,47]. Likewise, immature pods and grains contain high levels of protein and essential minerals, including potassium, calcium, zinc, and iron, thereby supporting healthy diets and encouraging greater legume production in Europe, particularly in southern regions [48,49].

The high nutritional quality of cowpea makes it an important crop for addressing malnutrition and micronutrient deficiencies, especially in low-income communities and developing countries where access to diversified diets is limited and cowpea is widely cultivated [42–44,50–52].

Beyond its role in human nutrition, cowpea is a multifunctional crop with significant value for livestock production and sustainable agriculture. Its protein-rich seeds and vegetative biomass are widely used as animal feed, either alone or in combination with forage crops such as sorghum and rye for hay and silage production [53,54]. Cowpea has attracted growing interest as an alternative protein source for livestock feeding, particularly in poultry production, where it has the potential to reduce dependence on imported soybean meal. Studies have shown that the inclusion of cowpea protein hydrolysates in broiler diets can positively influence metabolic activity and immune responses [54,55]. Research conducted in Romania further demonstrated that the total or partial replacement of soybean meal with cowpea grain in broiler feed resulted in comparable zootechnical performance, including body weight, average daily gain, feed intake, and feed conversion ratio, with no significant differences between treatment groups [54]. Moreover, chickens fed cowpea-based diets exhibited improved breast and thigh meat quality, characterised by higher protein and collagen contents compared with

those receiving soybean meal [54]. These findings highlight cowpea as a promising, cost-effective protein source for animal feed, particularly in countries such as Romania, where poultry diets rely heavily on imported soybean meal.

Despite its nutritional and agronomic advantages, cowpea contains several antinutritional compounds that may reduce nutrient availability, particularly for humans and non-ruminant animals. Consequently, various processing techniques are commonly applied to reduce or eliminate these compounds and enhance nutrient digestibility and bioavailability [56]. The overall nutritional value of cowpea, however, is influenced by multiple factors, including genotype, agroclimatic conditions, cultivation practices, and post-harvest management, all of which affect the composition and quality of both the edible seeds and vegetative biomass [48].

2.4. Cowpea as a Soil-Improving Crop

Cowpea contributes significantly to sustainable agriculture through its capacity to improve soil fertility and reduce dependence on synthetic nitrogen fertilisers. As a leguminous crop, it forms a symbiotic association with nitrogen-fixing bacteria of the genus *Bradyrhizobium*, which colonise specialised root nodules. Through biological nitrogen fixation, cowpea can satisfy approximately 80–90% of its nitrogen requirements, substantially reducing mineral nitrogen inputs and associated production costs while enhancing plant growth, development, and drought tolerance under climate change conditions [4,56–59].

The agronomic benefits of biological nitrogen fixation extend beyond the cowpea crop itself. When incorporated into crop rotations or used as green manure, cowpea enriches the soil with biologically fixed nitrogen and organic matter, improves nutrient cycling, enhances soil fertility, and reduces the nitrogen fertiliser requirements of subsequent crops [45–47,60–63]. These practices are particularly important for sandy soils, where intensive cultivation has depleted soil organic carbon and nutrient reserves, making soil fertility restoration a major challenge [64–67].

Numerous studies have demonstrated the positive effects of cowpea on subsequent crops and soil quality. In Burkina Faso, incorporating cowpea into crop rotations increased sorghum yields by up to 290% compared with continuous sorghum monoculture [68]. In Colombia, the use of cowpea as green manure in sugar beet production reduced the nitrogen fertilizer requirement from 138 to 119.3 kg N ha⁻¹ after four cropping cycles [42], while in India, green manure application increased menthol mint fresh biomass by 23.4% and essential oil yield by 25.2% compared with unfertilised controls [63].

Research conducted in Romania further confirms the value of cowpea for improving the productivity of sandy soils. Isotopic ¹⁵N studies showed that cowpea obtains approximately 80–90% of the nitrogen required for biomass production through symbiotic nitrogen fixation, whereas the efficiency of applied nitrogen fertiliser was only 4.4% because of substantial nitrogen losses through leaching. The same study demonstrated that applying a starter fertilisation of 30 kg N ha⁻¹ together with 25 kg Mg ha⁻¹ at sowing enhanced biological nitrogen fixation [59]. In addition, annual incorporation of 52.4 t ha⁻¹ of fresh cowpea biomass (9.24 t ha⁻¹ dry biomass) as green manure in a sorghum–cowpea–rye rotation significantly improved sandy soil quality, increasing total nitrogen, available phosphorus, exchangeable potassium, and soil organic carbon, while reducing soil acidity and improving water-holding capacity [44]. These findings highlight cowpea as an effective nature-based solution for restoring degraded sandy soils and increasing the sustainability and resilience of cropping systems under climate change.

3. Materials and Methods

In terms of literature search and selection strategy, this review used a structured search following PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines to identify scientific literature on cowpea cultivation under drought conditions and on sandy soils. The final literature search was conducted on 29 May 2026 across five major scientific databases: Web of Science, Google Scholar, Scopus, ScienceDirect and SpringerLink. The search was executed using combinations of keywords across seven thematic categories: (1) cowpea-specific plant for sandy soils; (2) biological requirements and improvement of the cowpea; (3) cowpea and atmospheric nitrogen fixing plant; (4) green cowpea fertilizer; (5) abiotic factors in cowpea (fertilization, sowing, prevention and control of harmful agents (weeds, diseases, pests); (6) water consumption and irrigation in cowpea; (7) cowpea quality. A representative search string used was: “cowpea” or “*Vigna unguiculata*” and “sandy soil” or “drought” and “nitrogen fixation” or “irrigation”.

The selection workflow is fully detailed in the PRISMA flow diagram (Figure 1). A total of 416 records were identified from the initial database search. Prior to screening, 18 duplicate records were removed, leaving 398 records screened based on titles and abstracts. From these, 76 records were excluded as non-relevant. A total of 322 reports were sought for retrieval, of which 6 reports could not be retrieved, leaving 316 full-text reports assessed for eligibility. Following detailed full-text assessment, 189 reports were excluded based on specific criteria: not directly related to cowpea, lack of focus on drought or sandy soils, non-scientific source type, insufficient methodological detail or duplicate data. Ultimately, 127 studies and professional websites were included in the final synthesis.

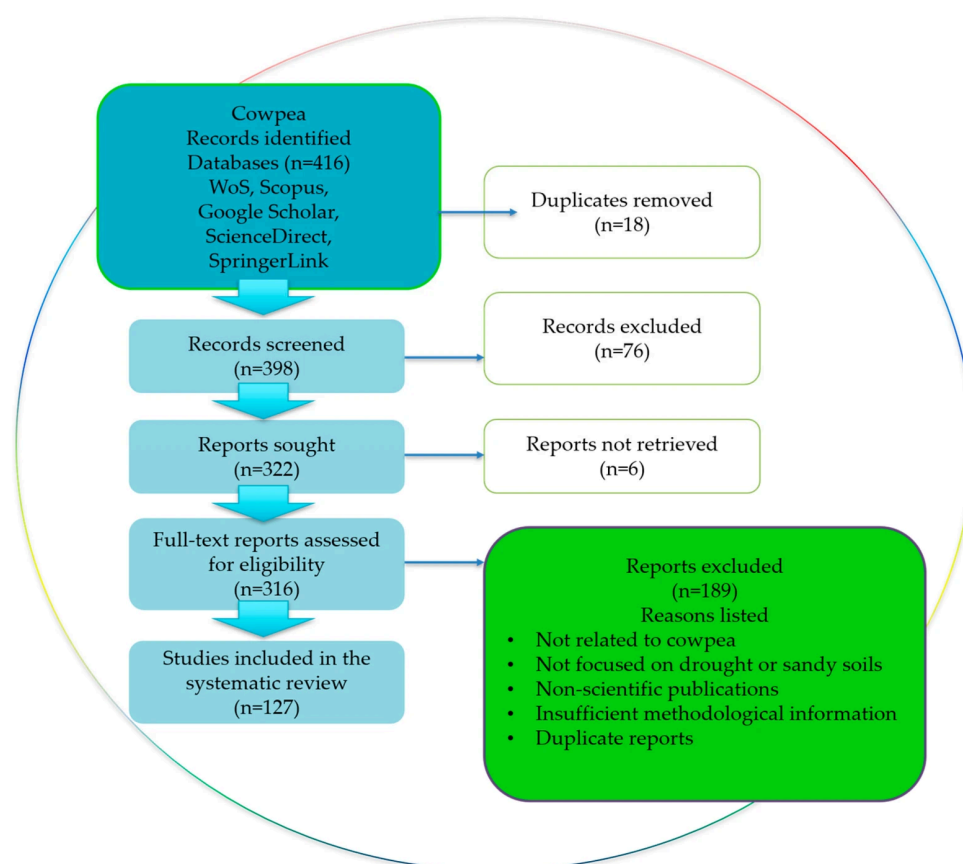


Figure 1. Prisma diagram of the methodological workflow.

The selected studies, published in English and Romanian, were synthesized to ana-

lyze the biological characteristics, agronomic management, drought adaptation mechanisms, biological nitrogen fixation capacity, soil improvement potential, nutritional value and practical application of cowpea in sustainable agricultural systems on sandy soils.

4. Results

4.1. Natural Resources and Environmental Requirements for Cowpea Cultivation

4.1.1. Soil Conditions

In terms of the plant's requirements for natural soil fertility, cowpea is considered a plant with low demands, making good use of loamy sand and loamy fine sandy soils, alfisol soils that have a base saturation degree of over 35%, which means that they retain significant amounts of calcium, magnesium, potassium and sodium, and sandy soils [69,70]. During the cowpea growing season, the average air temperature was 23.08 °C, with a maximum of 41.21 °C [47,71,72].

Studies conducted in Brazil have also demonstrated cowpea's tolerance to saline conditions. Plant growth and yield were found to depend largely on soil type, with Alfisols outperforming Ultisols despite accumulating higher salt concentrations under saline irrigation, thereby providing more favourable conditions for cowpea development and productivity (Table 2) [70].

Table 2. Productivity of the cowpea in different climate and soil conditions.

Reference	Area	Soil Type	Soil Properties	Annual Precipitations (mm)	Air Temperature (°C)	Yield Kg/ha
[69]	Nigeria	loamy sand, loamy fine sand	OC: 0.81–0.91% pH: 6.1–6.2	1278	15–38	730–766
[70]	Brazilia	Alfisol (EC of 3 dS m ^{−1})	EC (dS m ^{−1}): 0.8 pH: 6.7	1800	27–39	2500
[72–76]	Romania	Sandy soils	OC: 0.67–0.69%; pH: 6.86–6.93	556,77	11,69	1500–2500

Romania has approximately 439,000 ha of sandy and sandy soils, of which about 209,400 ha are located in the Southwest of the country (Oltenia region). They are characterised by low natural fertility (less than 1.2% humus) and poor hydrophysical properties, emphasising the need for sustainable strategies to improve their agricultural utilisation [71,72]. Most Romanian studies on cowpea cultivation have been conducted at the Research and Development Station for Plant Culture on Sandy Soils Dăbuleni (SCDCPN Dabuleni), Romania (43°48'3" N, 24°05'33" E, 55 m asl), located in southern Romania (Oltenia region), where approximately 80,000 ha of the sandy soils situated on the left bank of the Jiu River are concentrated [73] (Figure 2).

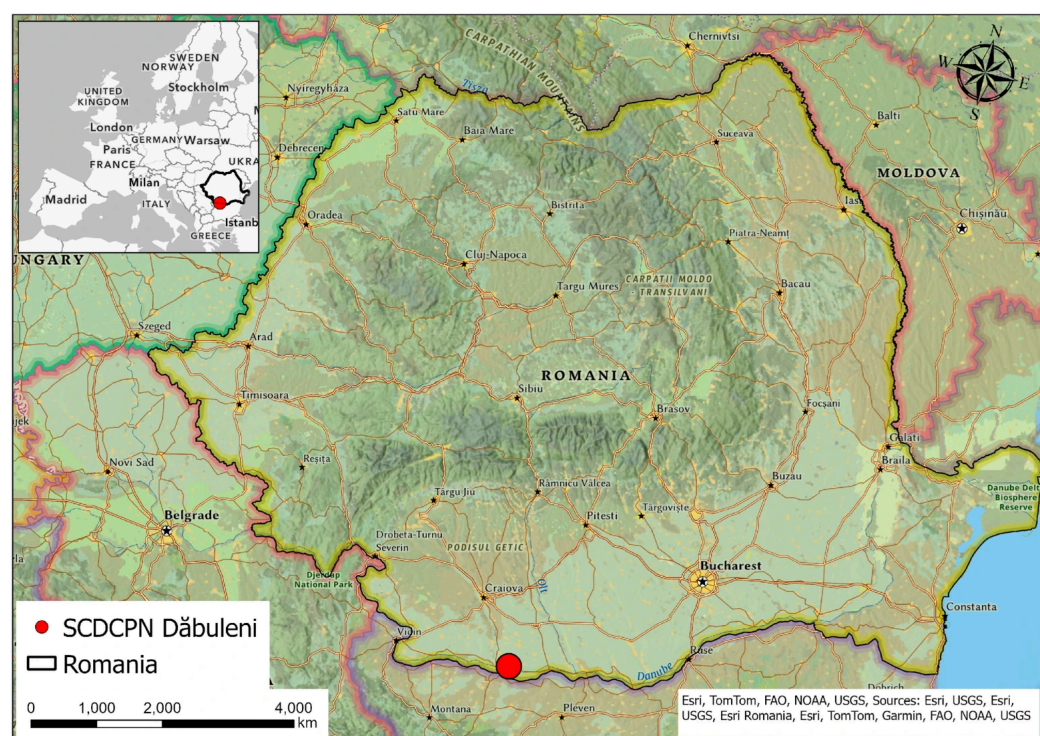


Figure 2. Location of the sandy area in Southern Romania.

These soils are characterized by low bulk density within the upper 1.0 m soil profile ($1.42\text{--}1.52\text{ g cm}^{-3}$), resulting in a loose soil structure and moderate-to-high total porosity [74]. Their hydrophysical properties include a low permanent wilting point ($1.1\text{--}2.1\%$) and a limited field capacity ($7.5\text{--}9.3\%$). Soil reaction ranges from neutral to slightly acidic, while humus content generally remains below 1%. Owing to intensive leaching processes, the availability of nitrogen, phosphorus, and potassium is below the nutritional requirements of most agricultural crops [77]. The combined deficiencies in nutrients, organic matter, and clay lead to inherently low soil fertility, underscoring the importance of selecting crop species that can enhance the productive potential of these fragile ecosystems [75,78].

Research conducted in Romania has further shown that the soil water content of sandy soils frequently falls outside the optimum range required by most cultivated plant species, thereby constituting a major stress factor that adversely affects plant physiological processes [79].

Appropriate crop selection according to soil fertility and environmental conditions is therefore essential for enhancing plant resilience to abiotic stress. In this respect, cowpea, often referred to as the “queen of psammosol areas”, represents a suitable crop for promoting sustainable agricultural systems in drought-prone regions with low-productivity sandy soils, owing to its excellent adaptation to these ecological conditions [80,81].

4.1.2. Climatic Conditions and Their Impact on Crops

Climate change represents one of the greatest global threats to food and nutritional security [82,83]. Studies investigating long-term climatic trends in Romania during the period 1901–2023 have revealed a progressive increase in air temperature accompanied by a significant decline in precipitation, both of which have become major limiting factors for the growth and productivity of agricultural crops [84]. Annual climate data, derived from the observations recorded by the National Meteorological Administration Network of Romania, and freely available from the Romania’s Climate Change Adaption

National Platform (RO-ADAPT) (<https://www.roadapt.ro/geoportal-harta-interactiva.php> (accessed on 21 July 2026)) [85] highlighted insignificant changes in precipitation (PREC) and statistically significant increasing trends in average temperature, indicating a general warming in the 20th century and the first decades of the 21st century, with negative implications for the growth and development of most spring crops (Figure 3).

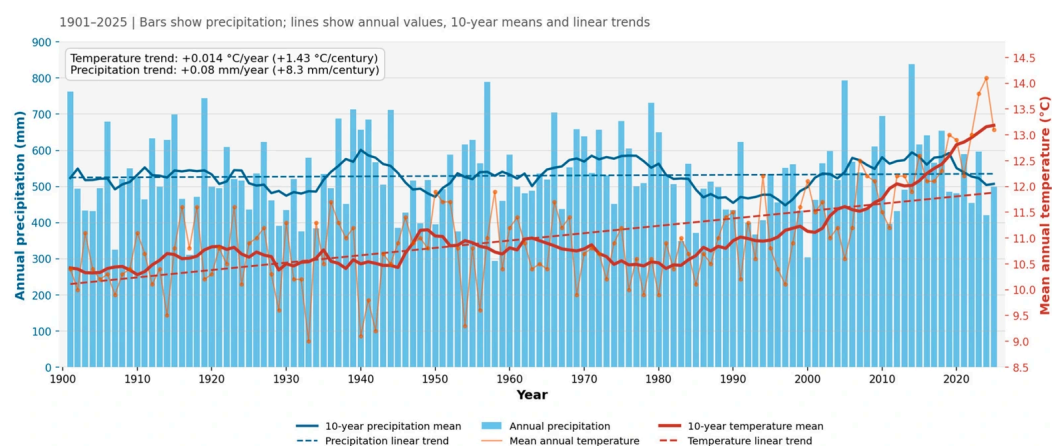


Figure 3. Mean annual temperature and precipitation as derived from Romania’s Climate Change Adaptation National Platform (RO-ADAPT), over the period 1901–2025, for Romania (<https://www.roadapt.ro/geoportal-harta-interactiva.php> (accessed on 21 July 2026)).

As a consequence of global warming, desertification has become increasingly evident in southern and southwestern Romania. In these regions, soil structure is weak and highly susceptible to degradation; wind erosion promotes the movement of sand dunes, causing considerable damage to crops during the early stages of plant development [20,74]. Climatic analysis shows that this area has a multiannual average air temperature of 11–12 °C and an annual precipitation amount of approximately 550–580 mm, with a soil water deficit during the summer [75,85].

Meteorological observations conducted in the SCDCPN Dabuleni, using the iMetos 3.3 weather station (produced by Pessl Instruments) during the summer months (June–July) of 2024 and 2025 recorded average monthly air temperatures exceeding the long-term average (1956–2024) by 2.76–3.12 °C, together with monthly precipitation deficits ranging from 36.73 to 47.32 mm [76]. Combined with low relative air humidity, these climatic conditions create an arid microclimate that severely constrains the growth and productivity of most spring-sown crops and, consequently, affects the sustainability of agricultural production in drought-prone areas.

The climatic conditions prevailing during the reproductive stage are particularly critical for grain legumes. High air temperatures, reaching maximum values of 40.00–42.00 °C, together with extremely low relative humidity (minimum values of 13.00–14.00%), cause pollen sterility and severe yield losses in common bean. Under the same environmental conditions, cowpea maintains its reproductive capacity by producing multiple flowers on each flowering stem, allowing successful pollination and pod set when favourable microclimatic conditions are restored [75,86]. In addition, stomatal closure represents one of the principal physiological mechanisms through which cowpea minimizes leaf water loss and enhances drought tolerance [63,87].

Depending on the timing and severity of drought, water deficit may result in delayed or incomplete emergence, reduced vegetative growth, shortened growing season, and reduced size of reproductive organs. Compared with common bean and soybean, cowpea maintains more stable physiological performance under drought conditions ow-

ing to its well-developed root system with high water-uptake capacity, the protective waxy layer covering the leaves, and favourable stomatal characteristics. The number of stomata on the adaxial leaf surface ranges from 139 to 143 stomata mm^{-2} under rainfed and irrigated conditions, respectively, contributing to the efficient regulation of plant water status under contrasting environmental conditions [88].

Continued growth of the canopy and root system intensifies intraspecific competition among cowpea plants during the growing season. Studies have shown that biomass accumulation increases when the crop is cultivated under agroecological conditions that closely resemble those of its centre of origin, highlighting the importance of environmental adaptation for maximising plant performance [89].

Cultivated worldwide across diverse agroecological regions, cowpea is highly tolerant of heat, drought, and low soil fertility. These adaptive characteristics enable the crop to thrive in areas with erratic rainfall and unfavourable growing conditions. Its remarkable adaptability, together with its ability to fix atmospheric nitrogen, makes cowpea an essential crop for semi-arid regions, where agricultural production largely depends on rainfall [36].

Given its thermal requirements, Romania lies near the northern limit of the climatic suitability range for cowpea cultivation [73]. Nevertheless, the sandy soil region of southern Romania provides a particularly favourable microclimate that supports optimal plant growth and development. This explains the successful cultivation of cowpea in an area where other grain legumes, particularly common bean and soybean, often yield poorly due to severe heat and drought stress. Under these environmental conditions, cowpea represents a promising alternative to the cultivation of common bean and soybean in regions frequently affected by prolonged drought.

The literature indicates that all major physiological processes of cowpea, from germination to the end of the growing season, require relatively high temperatures exceeding 10 °C [63,90]. Such thermal conditions are consistently recorded in southern Oltenia and generally persist throughout September and October, allowing cowpea to be successfully cultivated as a double crop after the main crop harvest. Under these conditions, the crop maintains soil cover until approximately 15–20 October, contributing to more efficient land use and improved sustainability of cropping systems.

Results from the current research project, ExoCrop—“EXploring Climate Opportunities and assessing the favoRability of Romania’s terRitory for Optimized and High-Performance agRiculture” highlighted the cowpea growth season phenology and climatic data from the research station Dăbuleni, Romania. Precipitation was insufficient throughout the growing season to satisfy the crop water requirements; therefore, irrigation was applied (Supplementary Table S1). Such thermal conditions are consistently recorded in southern Oltenia and generally persist throughout September and October, allowing cowpea to be successfully cultivated as a double crop after the main crop harvest. Under these conditions, the crop maintains soil cover until approximately 15–20 October, contributing to more efficient land use and improved sustainability of cropping systems.

4.2. Development of Cowpea Research in Romania in the Context of Global Research Advances

The progressive increase in air temperature recorded in Romania over recent decades, together with the presence of approximately 439,000 ha of sandy soils characterised by low natural fertility (less than 1.2% humus) and poor hydrophysical properties, has highlighted the need for sustainable strategies to improve the agricultural use of these marginal lands. Within this context, research on cowpea in Romania has focused on both genetic improvement and the evaluation of crop responses to major abiotic and

agronomic factors, including sowing practices, fertilisation, weed pressure, natural infestation by diseases and pests, and irrigation management.

Investigations addressing the interactions among plants, soil, and climate are particularly relevant for maximising the biological and economic potential of cowpea, a crop well adapted to arid environments. These research directions are fully aligned with the *Romanian National Strategy for Mitigating the Effects of Drought and Combating Land Degradation and Desertification*, developed by the Ministry of Agriculture and Rural Development [91]. Given its high tolerance to heat and drought, together with its nutritional and agronomic value, cowpea is increasingly recognised as a strategic crop for climate-resilient agriculture. Consequently, the conservation of genetic resources and the optimisation of cultivation technologies represent essential priorities for promoting this species within sustainable agricultural systems in response to increasing drought frequency and the growing global demand for plant-based protein.

4.2.1. Advances in Cowpea Breeding

The widespread cultivation of cowpea across diverse climatic, geographic, and edaphic regions has exposed the species to both natural and artificial selection, resulting in considerable genetic diversity and the development of locally adapted populations [11,23,24,28,57,92,93]. Consequently, breeding programs have focused on developing cultivars specifically adapted to the environmental conditions of different production areas.

Over the years, breeding efforts have increasingly targeted the development of early-maturing cultivars with enhanced tolerance to drought, diseases, and pests [94–96]. In general, cowpea improvement programs aim to combine high grain yield and superior seed quality with increased resistance to both biotic and abiotic stresses. This growing interest reflects not only the crop's potential to strengthen food and nutritional security but also its valuable contribution to improving soil fertility within sustainable cropping systems [56,97].

Although cowpea cultivation has a much shorter history in Europe and the Americas than in Africa, breeding initiatives have expanded considerably in recent years. In Romania, research on cowpea improvement and cultivation technology gained momentum during the transition toward sustainable agriculture, primarily driven by the need to increase agricultural productivity on sandy soils, where the cultivation of other grain legumes is frequently limited by unfavourable environmental conditions [74,98]. Ensuring food security requires continuous genetic progress based on the evaluation, conservation, and effective utilisation of available germplasm resources adapted to local agroecological conditions [99,100].

Between 2016 and 2021, in Romania, 130 traditional cowpea genetic resources were evaluated and preserved. The study revealed substantial variability in biological and morphological traits, highlighting their considerable potential for future breeding programs [19]. Evaluation of vegetative growth characteristics, including plant height and the number of shoots per plant, showed high variability ($CV = 28.77\text{--}36.93\%$). Plant height ranged from 33.4 to 164.2 cm, with a mean value of 100.8 cm, whereas the number of shoots varied from 0.5 to 6.0 per plant, averaging 2.6 shoots per plant.

Similar results were reported in India, where 28 cowpea genotypes also exhibited substantial phenotypic variability [96]. Under Indian conditions, mean plant height reached 73.27 cm (38.3–80.5 cm), the average number of pods per plant was 16.77 (13.0–20.5), and the mean number of seeds per pod was 13.5, ranging from 7 to 15. Likewise, studies conducted in Bulgaria demonstrated the region's suitability for early-maturing cowpea cultivars with a growing period of approximately 72 days. Based on the phenotypic evaluation of ten genotypes, three accessions (A4E0084, A4E0081, and A4E0007)

were identified as the most promising breeding materials owing to their favourable biological and physiological characteristics and their potential to meet farmers' requirements [101].

Plant growth habit represents another important selection criterion in cowpea breeding. Among the 130 Romanian cowpea genotypes evaluated, 46.9% exhibited an erect, determinate growth habit suitable for grain production, 33.1% showed an erect, indeterminate growth habit appropriate for forage production, and 20.0% displayed a prostrate growth habit, making them suitable candidates for green manure production [68].

Statistical analysis further demonstrated that cowpea grain yield was closely associated with resistance to viral diseases and pod-setting ability (Figure 4). Grain yield was positively correlated with the number of pods per plant and negatively correlated with disease susceptibility, emphasising the importance of these traits in breeding programs aimed at improving cowpea productivity [19].

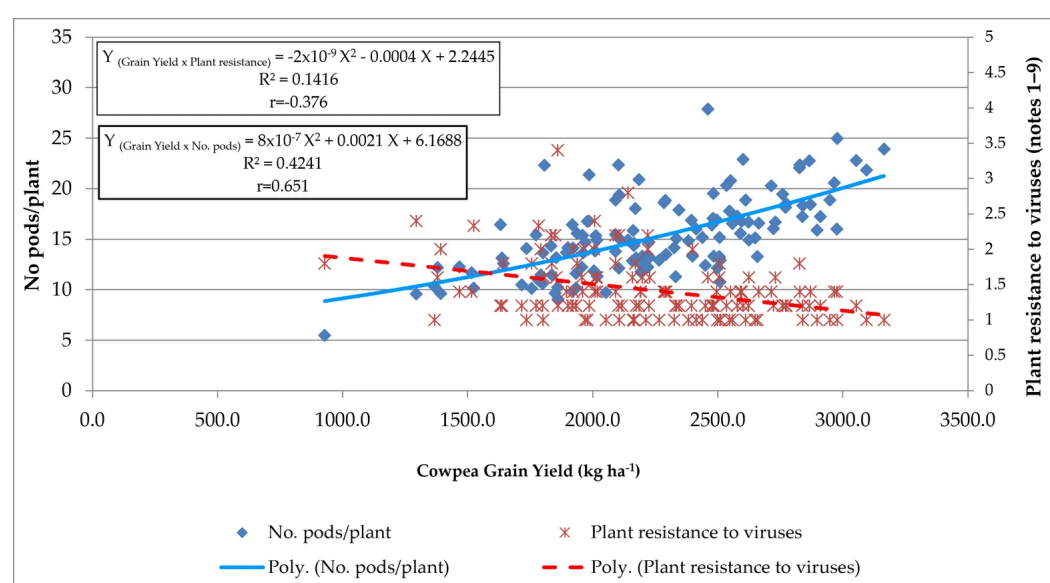


Figure 4. Correlations between cowpea production and virus resistance and the pod setting process at the collection level of cowpea cultivars and lines [19]. [$r=0.651$ and $r=-0.376$ represent significant correlation coefficients (**) for $p \leq 0.05$ (correlation coefficients for 130 studied variants that can be considered different from zero)].

As a result of long-term breeding efforts, five cowpea cultivars have been developed in Romania. The first one, 'Jiana', was released in 1976 by the Faculty of Agronomy at the University of Craiova and is a late-maturing cultivar primarily intended for green biomass production. Subsequently, the cultivars 'Aura', 'Ofelia', 'Aura 26', and 'Doljana' were developed at SCDCPN Dăbuleni and released in 1997, 1998, 2012, and 2017, respectively. These cultivars were bred for grain production and possess morphological characteristics that make them suitable for mechanical harvesting [19,20].

The evaluation of eight advanced cowpea breeding lines in Romania (Figure 5) revealed significant genotypic differences in leaf area index (LAI), with values ranging from 4.54 to 6.04. LAI was positively correlated with plant height and negatively correlated with the number of pods per plant, indicating that excessive vegetative development may reduce grain productivity. A dense canopy limits light penetration to the standard petal (vexillum), which plays an essential role in flower opening, pollination, and successful fertilisation, ultimately affecting pod set and grain yield. Similar findings have been reported in China, where plant architecture, particularly an erect growth

habit, was identified as a key determinant of cowpea grain yield [102].

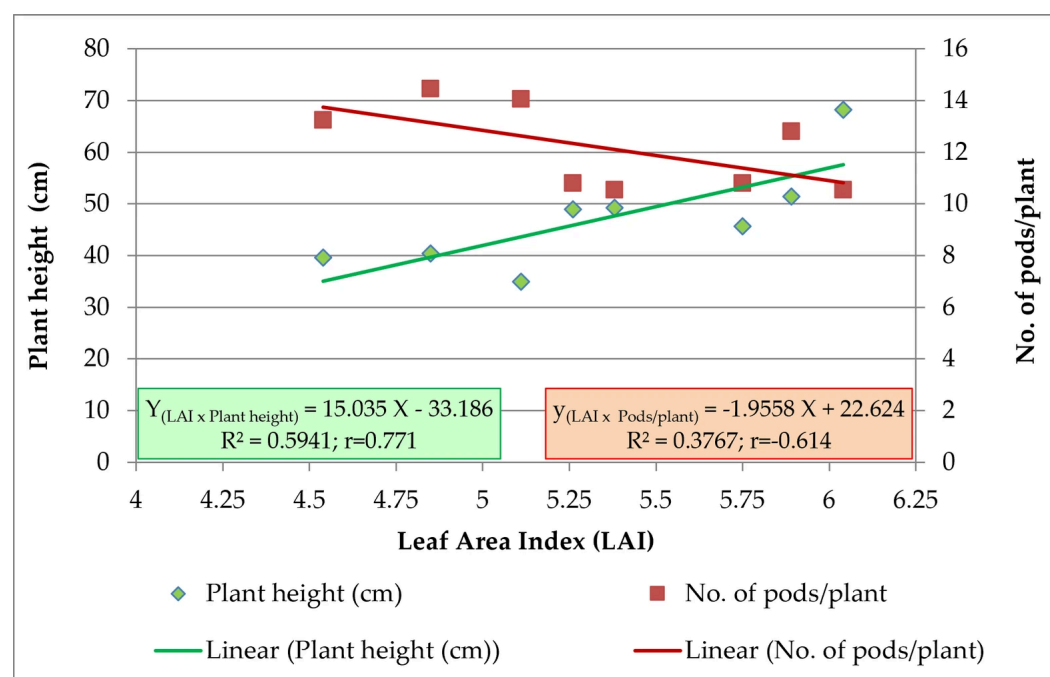


Figure 5. Correlations between the leaf area index recorded in the flowering phase of broad cowpeas with plant height and the number of pods per plant [76]. [$r=0.771$ represent a significant positive correlation coefficient (*) at $p\ 5\%>0.71$ (correlation coefficients for 8 studied variants that can be considered different from zero)].

Under the dry climate conditions of Southern Romania, the eight cowpea genotypes were developed under relatively high temperatures ranging from 16.1 to 26.5 °C, with a mean daily temperature of 23.8 °C. During the growing season, cumulative thermal resources ranged from 1637.8 to 2040.1 °C, while the crop cycle lasted between 69.5 and 85 days [76].

Physiological measurements for cowpea plants revealed pronounced diurnal variations in photosynthesis and transpiration. The highest rates were recorded during the morning (09:30 h), when leaf temperature, measured using an LCD Pro SD portable analyser (ADC BioScientific), ranged from 32.7 to 37.2 °C. As leaf temperature increased to 40.0–44.4 °C at 12:00 and 15:00 h, stomatal closure occurred, resulting in a marked reduction in photosynthetic activity. Consequently, the net CO₂ assimilation rate declined to only 0.93–10.35 μmol CO₂ m⁻² s⁻¹, while transpiration decreased to 0.09–3.78 mmol H₂O m⁻² s⁻¹. Stomatal aperture is widely recognised as a key indicator of plant responses to heat and drought stress [103]. In cowpea cultivated on the sandy soils of Romania, stomatal conductance varied between 0.02 and 0.16 mol H₂O m⁻² s⁻¹ and directly influenced both photosynthetic activity and leaf transpiration. Statistical analysis (Figure 6) revealed highly significant positive correlations between stomatal conductance and both physiological processes, confirming the central role of stomatal regulation in plant adaptation to water deficit.

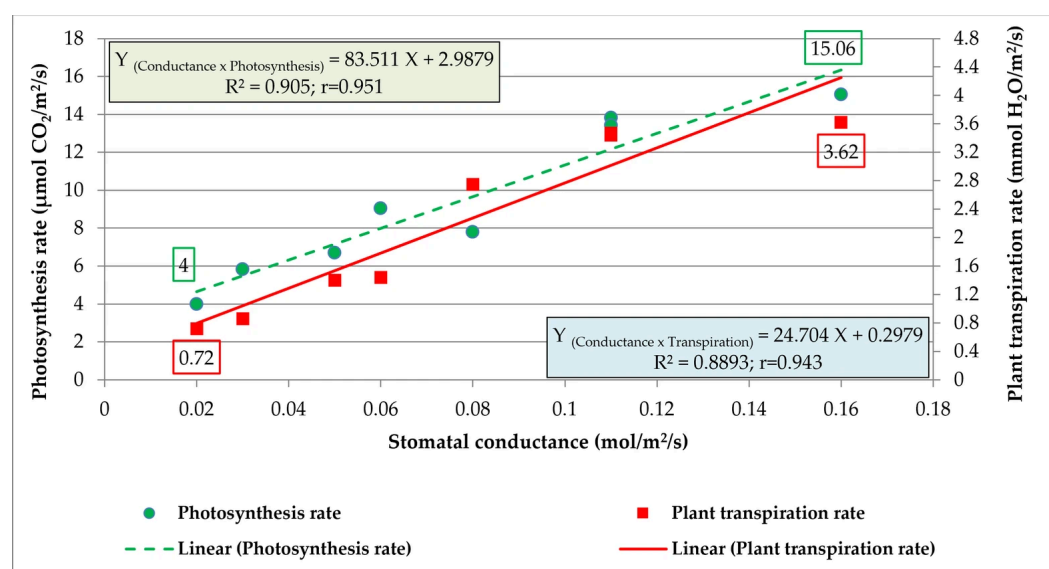


Figure 6. Correlations between stomatal conductance and photosynthesis and transpiration processes recorded in cowpea [76]. [$r=0.951$ and $r=0.943$ represent significant positive correlation coefficients (**) at $p > 0.83$ (correlation coefficients for 8 studied variants that can be considered different from zero)].

Stomatal closure is one of the main drought-tolerance mechanisms in cowpea. The species can therefore be classified as a conservative or water-saving plant, prioritising the maintenance of leaf water status and turgor over maximum photosynthetic activity under stress conditions [57].

4.2.2. Good Agricultural Practices for Cowpea Cultivation in Romania

The expansion of arid regions and the increasing severity of desertification require new strategies for the sustainable use of sandy soils and other marginal lands. These approaches should integrate conventional agronomic practices with innovative technologies to mitigate the adverse effects of climate change on key physiological processes involved in carbon assimilation, including photosynthesis, transpiration, and respiration.

Cowpea is a drought-tolerant grain legume widely cultivated by smallholder farmers in sub-Saharan Africa and other warm regions characterized by limited rainfall. However, its productivity remains strongly influenced by both biotic and abiotic stress factors [7,73].

(i) Sowing Management

Owing to its tropical origin, cowpea is a thermophilic crop that requires relatively high temperatures throughout its entire ontogenetic development, from seed germination to physiological maturity. Seed germination is closely associated with both air and soil temperatures [73,104]. Under Romanian conditions, the accumulation of total thermal resources ranging from 57.6 to 96.8 °C in the air and from 180.0 to 207.2 °C at the ground level resulted in seedling emergence of the cowpea cultivar ‘Aura’ within eight days after sowing, with an emergence uniformity of 96.8–100% [77]. The interval between sowing and emergence depends not only on temperature magnitude but also on temperature stability during this period. Field observations have shown that suboptimal temperatures prolong germination and adversely affect the development of the root system, hypocotyl, epicotyl, and primary leaves.

Exposure to temperatures of only 5–7 °C during germination may cause hypocotyl twisting, radicle decay, and even disruption of root geotropism, resulting in roots growing toward the soil surface where daytime temperatures increase more rapidly [77,105].

Under such conditions, the taproot frequently develops a spiral- or hook-shaped curvature immediately below the root collar, adversely affecting the subsequent growth and development of the entire plant. By contrast, seedlings emerging under optimal temperatures ($>10\text{ }^{\circ}\text{C}$) develop a straight, vertically oriented taproot from the root collar.

The production of vigorous and healthy cowpea seedlings also depends on seed storage conditions and storage duration. Previous studies have demonstrated a progressive decline in seed germination capacity with increasing storage time [105]. Temperature is therefore considered the primary climatic factor regulating the physiological processes of cowpea. Research conducted in Romania has shown that, under sandy soil conditions, cowpea should be sown when the soil temperature at sowing depth reaches $12\text{--}15\text{ }^{\circ}\text{C}$ [75]. Under the climatic conditions of southern Romania, these temperatures are usually attained between the last decade of April and the first decade of May, when both soil and air temperatures become relatively stable. Large temperature fluctuations, which frequently occur during early April, prolong the period between sowing and emergence, resulting in reduced plant establishment and lower grain yields. Seedlings emerging after prolonged exposure to fluctuating temperatures around $10\text{ }^{\circ}\text{C}$ are generally weaker and less vigorous than those established under optimal thermal conditions.

Optimising plant density is a key component of cowpea crop management because it determines the balance between genotype, soil, climate, and agronomic practices, thereby directly influencing grain yield while minimizing additional production costs [105]. Plant competition for solar radiation, water, and nutrients becomes particularly important on sandy soils, where interactions among neighbouring plants intensify during canopy and root system development. Under these conditions, the crop should provide sufficient soil cover to reduce excessive soil heating while ensuring that each plant has adequate access to water and mineral nutrients for optimal growth and development [79]. Numerous studies have demonstrated the close relationship between cultivar characteristics and plant spacing in cowpea [18,75,106]. Plant density directly influences plant growth and development and, consequently, final grain yield. Research conducted under irrigated conditions on the sandy soils of Romania showed that the highest grain yields were obtained at sowing densities of $20\text{--}25$ viable seeds m^{-2} . Compared with the treatment of 10 viable seeds m^{-2} , which produced 1814 kg ha^{-1} , these sowing densities increased grain yield by $416\text{--}483\text{ kg ha}^{-1}$, with statistically significant differences [73]. Increasing plant density beyond this optimum resulted in a decline in grain yield.

Mathematical analysis of the functional relationship between the number of viable seeds sown and grain yield in the Romanian cowpea cultivar ‘Ofelia’ revealed a highly significant positive correlation [18]. Economic optimisation further indicated that the maximum grain yield could be achieved at a sowing density of approximately 20.6 viable seeds m^{-2} .

Overall, these studies demonstrate that optimising plant density according to genotype and local environmental conditions is essential for maximising cowpea productivity. Although the optimum density varies across production environments, an adequate plant population remains one of the most effective and economical agronomic practices for improving grain yield.

To achieve the recommended plant density of $20\text{--}25$ plants m^{-2} , studies conducted in Romania recommend a seed rate of approximately $25\text{--}30\text{ kg ha}^{-1}$, depending on variety [75].

(ii) Nutrient Management

The inherently low fertility of sandy soils, resulting from their low organic matter content and limited reserves of essential nutrients, together with the rapid depletion of

micronutrients under irrigated conditions, requires the application of fertilisers to sustain crop productivity. However, the large amounts of mineral fertilisers often required on these soils may increase the risk of nitrate leaching into groundwater because of their poor hydrophysical properties and limited nutrient retention capacity [74,107]. Deficiencies in micronutrients, particularly Zinc and Magnesium, are also frequently observed, underscoring the need for balanced fertilisation of both macro- and micronutrients [108,109].

Sustainable increases in crop productivity depend on maintaining an appropriate balance among soil fertility, climatic conditions, and sound land management practices, since soil fertility is strongly influenced by both natural processes and anthropogenic activities [110]. Although cowpea is generally regarded as a crop with relatively low nutrient requirements, poor soil fertility remains a major constraint on its productivity. Research has also demonstrated that deficiencies of even a single essential nutrient or inadequate agronomic management may substantially reduce crop productivity on sandy soils [111].

Several sustainable approaches have recently been proposed to improve the fertility of sandy soils. Research conducted under the sandy soil conditions of Romania has demonstrated the importance of applying a basal fertiliser dose of $N_{60}P_{60}K_{60}$ that was applied in two fractions ($\frac{1}{2}$ in the preparation of the germination bed and $\frac{1}{2}$ in the phase of 4–5 true leaves), followed by foliar fertilisation to improve both physiological performance and grain yield [20,108]. The highest grain yields ($2746.2\text{--}2782.3\text{ kg ha}^{-1}$) were obtained when foliar fertilisation was applied at the 6–8 leaf stage using either Basfoliar[®] 36 Extra SL at 3 L ha^{-1} or Maturevo[®] 3-35-35 + ME at 3 kg ha^{-1} , both treatments producing significantly higher yields than the unfertilized control [112] (Table 3).

Table 3. Products used in foliar fertilization in cowpea [112].

Fertilizer	Type	Chemical Composition
Maturevo [®] 3-35-35 + ME	Soluble foliar fertilizer with a high phosphorus and potassium content	Ntotal—3%; P_2O_5 —35%; K_2O —35%; Mg—1.5%; S—0.4%; B—0.1%; Fe—0.07%; Zn—0.03%; Mn—0.03%; Cu—0.006%; Mo—0.002%;
Basfoliar [®] 36 Extra SL	Liquid foliar fertilizer	Ntotal—27% (Urea nitrogen—18.7%; nitric nitrogen—4.7%; ammonia nitrogen—3.6%); MgO —3%; Mn—1%; By—0.2%; Fe—0.02%; B—0.02%; Zn—0.01%; Mo—0.005%

The positive response to Basfoliar[®] 36 Extra SL was primarily attributed to its high Magnesium content and readily available chelated micronutrients, which are rapidly absorbed through the leaves. Likewise, the high concentration of micronutrients, particularly magnesium, in Maturevo[®] 3-35-35 + ME helped maintain leaf photosynthetic activity for a longer period by preserving chlorophyll content and delaying leaf senescence. Furthermore, this fertiliser enhanced the selective uptake of nutrients from the soil, especially phosphorus and potassium, which are essential for reproductive development and stress tolerance.

Foliar fertilisation also improved cowpea's physiological response to environmental stress. The percentage of bound water in the leaves increased from 2.65% in the un-

treated control to 3.25–3.40% following foliar application of either Maturevo® 3-35-35 + ME or Basfoliar® 36 Extra SL. Similarly, vacuolar sap concentration, another physiological indicator of tolerance to hydrothermal stress, increased from 7.9% in the unfertilized control to 9.15–9.60% in the fertilised treatments [112].

(iii) Crop Health Management

Sandy soils are generally characterized by high weed infestation because weed seeds remain viable for longer periods under the well-aerated conditions and relatively low soil moisture that characterize these environments. Furthermore, irrigation, which is essential for crop production on sandy soils, creates favorable conditions not only for cultivated plants but also for the germination and development of weed species.

Weeds represent one of the major constraints to cowpea production. If not adequately controlled through appropriate crop management practices, they compete with the crop for water, light, and nutrients, ultimately reducing both yield and grain quality while increasing production costs [15,113].

Field observations conducted during 2019–2020 on an untreated and non-cultivated cowpea field established on sandy soils in southern Romania identified nine dominant weed species: *Ambrosia artemisiifolia* (68.14%), *Portulaca oleracea* (5.86%), *Amaranthus retroflexus* (1.06%), *Xanthium strumarium* (3.64%), *Atriplex patula* (4.71%), *Solanum nigrum* (0.09%), *Tribulus terrestris* (1.13%), *Digitaria sanguinalis* (13.73%), and *Cynodon dactylon* (1.64%) [114].

The same study demonstrated that the most effective weed control program consisted of pre-emergence application (after one-two days after cowpea sowing) of either Dual Gold® 960 EC (960 g L⁻¹ *S-metolachlor*) at 1.5 L ha⁻¹ or Stomp® Aqua (455 g L⁻¹ *pendimethalin*) at 4.0 L ha⁻¹, followed by post-emergence application of Fusilade® Forte 150 EC (150 g L⁻¹ *fluazifop-P-butyl*) at 1.5–2.0 L ha⁻¹ combined with either Corum® (480 g L⁻¹ *bentazone* + 22.4 g L⁻¹ *imazamox*) at 1.25 L ha⁻¹ plus 0.625 L ha⁻¹ of the adjuvant Dash® HC, or Benta® 480 SL (480 g L⁻¹ *bentazone*) at 3.0 L ha⁻¹. These chemical treatments were integrated with two mechanical inter-row cultivations.

Under this integrated weed management strategy, weed infestation at harvest, evaluated using the European Weed Research Society (EWRS) rating scale (1–9), [115], ranged from 2.0 to 2.7, whereas the untreated and non-cultivated control reached the maximum infestation score of 9. Grain yields ranged from 1922.6 to 2053.6 kg ha⁻¹ under herbicide treatments, compared with only 373.7 kg ha⁻¹ in the untreated control and 532.4 kg ha⁻¹ in the mechanically weeded but non-herbicide-treated plots, where weed infestation before harvest remained high (EWRS score = 8.3).

Failure to implement appropriate agronomic practices, particularly optimum plant density, may favor the development and spread of pathogens in cowpea crops [116–118]. Under favourable climatic conditions, diseases and insect pests may become major constraints to crop production, leading to substantial yield losses or, in severe cases, complete crop failure.

In Romania, phytosanitary evaluations of 15 cowpea genotypes cultivated on sandy soils identified two major viral diseases: *Cowpea mosaic virus* (CPMV), transmitted both by insect vectors and infected seeds, and *Cowpea aphid-borne mosaic virus* (CABMV), transmitted by aphids [119]. Among these, CABMV was the predominant virus. Four aphid species acting as vectors were identified on the apical shoots of cowpea plants: *Aphis fabae*, *Macrosiphum euphorbiae*, *Aphis gossypii*, and *Acyrtosiphon pisum* [119]. Previous Romanian studies have also demonstrated that breeding programs, together with appropriate phytosanitary management, have substantially improved cowpea resistance to diseases [58].

More recent investigations carried out during 2021–2022 on the Romanian cultivar

‘Aura 26’ revealed sporadic infections caused by *Colletotrichum lindemuthianum*, the causal agent of anthracnose, as well as by *Cowpea mosaic virus* (CPMV) and *Cowpea yellow mosaic virus* (CYMV) [118]. The same studies reported severe aphid infestations (*Aphis gossypii*, *Aphis fabae*, and *Aphis craccivora*), which are responsible not only for direct feeding damage but also for virus transmission. Among these, *Aphis gossypii* is considered one of the most destructive cosmopolitan aphid species affecting cowpea production worldwide [120–122].

Considering the available scientific evidence, sustainable disease and pest management strategies for cowpea cultivated on the sandy soils of Romania should prioritize environmentally friendly approaches, including the cultivation of resistant genotypes and the use of low-impact plant protection products [118]. Field experiments demonstrated the effectiveness of the biofungicide Polyversum[®], containing *Pythium oligandrum* M1 (1×10^7 oospores g⁻¹), together with the ecological insecticide Bioinsekt[®], formulated with neem oil, organic matter, beneficial microorganisms, essential oils, humic and fulvic acids, and *Trichoderma harzianum*. Two applications, performed at the 3–4 true-leaf stage and again at flower bud appearance at the stem nodes (BBCH 50–59), using Polyversum[®] at 0.1 kg ha⁻¹ and Bioinsekt[®] at 0.5–1.0 L ha⁻¹, provided the highest level of phytosanitary protection for the cultivar ‘Aura 26’. Under these treatments, disease severity was limited to only 0.79%, while plants exhibited enhanced stress tolerance through increased bound water content (3.42%), higher dry matter accumulation (20.23%), and increased vacuolar sap concentration (10.2%). These physiological improvements resulted in a grain yield of 2725.2 kg ha⁻¹.

Statistical analysis revealed a highly significant negative correlation ($r = -0.821$) between pest attack severity and grain yield, confirming the major impact of pest pressure on cowpea productivity.

These findings emphasize that effective storage management and appropriate pest control measures are essential for minimizing post-harvest losses in cowpea.

(iv) Irrigation Management

Global analyses of evapotranspiration in agricultural lands, irrigation water consumption, natural evapotranspiration, and renewable freshwater resources indicate that agriculture remains the largest consumer of water worldwide. In 2015, agricultural activities accounted for approximately 87% of global water consumption, while nearly 60% of global freshwater withdrawals were allocated to irrigation [123]. As climate change intensifies and drought periods become increasingly prolonged, effective strategies are required to mitigate the adverse effects of heat and water stress on crop performance. Owing to its high ecological adaptability, cowpea represents a valuable component of cropping systems in regions frequently exposed to drought and high temperatures.

The limited availability of water in sandy soils is primarily associated with their inherently low fertility, susceptibility to wind erosion due to the weak cohesion of sand particles, and high evaporative losses from the soil surface [124]. Consequently, irrigation is essential for maintaining adequate soil moisture both during periods of intense wind erosion and throughout the growing season. Compared with loamy or clay soils, sandy soils have a considerably lower capacity to retain plant-available water due to their high coarse-sand content and low levels of organic matter and clay. These unfavourable soil properties may be partially improved by incorporating green manure derived from leguminous crops or by applying organic soil amendments [47,125].

Flooding causes progressive degradation of chlorophyll, reduced photosynthetic capacity, and decreased shoot biomass accumulation. Therefore, rapid recovery of stomatal function following flooding is essential for restoring carbon assimilation during the reproductive stage.

These findings highlight the potential for using moderately saline water as an alternative irrigation source in regions facing freshwater shortages. Exceeding the salt concentration in irrigation water can cause reduced cowpea seed germination, leaf burns, slowed plant growth and development, or even soil degradation due to the accumulation of salts in the soil, which can affect not only the current crop, but also future ones [126].

Successful irrigation management requires accurate knowledge of crop water requirements under specific soil and climatic conditions. Even though cowpea is considered drought-tolerant, water deficits combined with high temperatures remain the principal abiotic factors limiting plant growth and productivity. The severity of these effects depends on the crop developmental stage, as well as on the duration and intensity of water stress. Water shortages during vegetative growth and flowering significantly reduce grain yield.

Research conducted under sandy soil conditions in Romania demonstrated that the water required for seed imbibition and germination is generally supplied by soil moisture reserves and rainfall during the first half of May [127]. However, if drought develops within the upper 0–20 cm soil layer during this period, an emergency irrigation of 150–200 m³ ha^{−1} is recommended. This study also showed that cowpea exhibits relatively slow vegetative growth during the first 30–40 days after emergence, when root system development predominates; therefore, irrigation is usually unnecessary during this stage. Crop water demand increases markedly after the development of the fourth and fifth leaves and reaches its maximum during flower initiation, flowering, and pod development, when an adequate water supply is essential to achieve high grain yields.

Cowpea required substantially less irrigation water than soybean to achieve satisfactory grain yields under the sandy soil conditions of Romania (Table 4) [127].

Table 4. Water consumption and sources of water supply for cowpea and soybean cultivated on sandy soils in Romania [127].

Crop	Mean Grain Yield (kg ha ^{−1})	Total Water Consumption (m ³ ha ^{−1})	Sources of Water Supply					
			Soil Water Reserves		Rainfall		Irrigation	
			%	m ³ ha ^{−1}	%	m ³ ha ^{−1}	%	m ³ ha ^{−1}
Cowpea	2570	4160	4	160	60	2500	36	1500
Soybean	3020	7340	6	450	34	2500	60	4480

To produce an average grain yield of 2570 kg ha^{−1}, cowpea obtained approximately 4% of its water requirement from soil water reserves, 60% from effective rainfall (precipitation events exceeding 5 mm), and only 36% from sprinkler irrigation. When irrigation water use was expressed relative to grain yield, cowpea exhibited a markedly higher irrigation water-use efficiency than soybean. The irrigation water requirement was only 0.58 m³ kg^{−1} of grain for cowpea, compared with 1.48 m³ kg^{−1} for soybean, indicating that soybean required nearly three times more irrigation water to produce one kilogram of grain. These results classify cowpea as one of the grain legumes with the lowest dependence on irrigation water under sandy soil conditions.

This superior water-use efficiency is further reflected in irrigation scheduling. In cowpea, irrigation is recommended when soil moisture decreases to one-third of the available water capacity within the upper 50 cm of the soil profile, whereas soybean requires irrigation at a considerably higher threshold, corresponding to two-thirds of the available water capacity within the same soil depth [127].

Although cowpea is widely recognised as a drought-tolerant crop, its water demand

increases markedly from flower bud initiation through pod formation and reaches its maximum during seed filling, when rainfall alone is generally insufficient to sustain optimum biomass accumulation and grain development. Due to its biological and morphological characteristics, cowpea has, compared to beans and soybeans, a very strong root system, with a great absorption capacity. As a defence reaction against the lack of water in the soil and to satisfy the water needs of the cowpea, the lateral roots no longer have the horizontal position characteristic of the first phases, but with time the position becomes oblique, and then they take a positive geotropic orientation, exploring the soil in non-irrigated conditions to a depth of about 2 m [73,127]. A better understanding of cowpea responses to rising temperatures across different water availability scenarios, as well as the interactions among these environmental factors, remains a major research priority and will contribute to the development of more sustainable irrigation management strategies under future climate change conditions.

(v) Recommended Management Practices for Cowpea Cultivation on Sandy Soils in Romania

A summarising table containing the practical information on sowing temperature, plant density, seeding rate, fertilisation, weed control, pest control, and irrigation, which are important for researchers, extension workers, and farmers [75], is presented in Supplementary Table S2.

5. Conclusions

In the current context of increasing climate aridity, identifying agricultural practices that mitigate the adverse effects of climate change on crop production has become a major priority for ensuring global food security. The literature reviewed clearly demonstrates that cowpea growth, productivity, and adaptability are strongly influenced by the complex interactions among climatic conditions, soil characteristics, and crop management practices.

Cowpea offers several agronomic and environmental advantages that make it particularly well-suited to sustainable agricultural systems, especially in regions affected by water scarcity and low soil fertility. Its high tolerance to drought, ability to fix atmospheric nitrogen, contribution to increasing soil organic matter, suitability as a preceding crop in crop rotations, and high nutritional value for both human and animal consumption support its wider adoption as an alternative to other grain legumes cultivated under stressful environmental conditions.

The evidence presented in this review also highlights the importance of conserving cowpea genetic resources and optimising cultivation technologies, including appropriate management of sowing, plant density, fertilisation, irrigation, and crop protection. These practices are essential for maximising crop productivity while improving resource-use efficiency under increasingly variable climatic conditions.

Overall, cowpea represents a strategic crop for climate-resilient agriculture and offers considerable potential for the sustainable utilisation of sandy soils in Romania and other regions facing similar environmental constraints. Future research should focus on breeding climate-resilient cultivars, improving water- and nutrient-use efficiency, and developing integrated crop management strategies to ensure stable yields under future climate scenarios.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/doi/10.3390/agronomy16151455>, Table S1. Cowpea phenology and climatic conditions monitoring during growing season 2025; Table S2. Management practices in cowpea cultivation [75,112].

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