

Article

Not peer-reviewed version

Effect of Green Cowpea Manure on the Quality Properties of Sandy Soils Under the Specific Conditions of the Dry Climate in Romania

[Reta Draghici](#) , [Stefan Nanu](#) ^{*} , Aurelia Diaconu , [Cristina Bîrsoghe](#) , Florentina Netcu , Alina Nicoleta Paraschiv , Milica Dima

Posted Date: 19 September 2024

doi: 10.20944/preprints202409.1461.v1

Keywords: cowpea; green cowpea manure; crop rotation; fertilization system; soil chemical quality; soil hydrophysical indices



Preprints.org is a free multidiscipline platform providing preprint service that is dedicated to making early versions of research outputs permanently available and citable. Preprints posted at Preprints.org appear in Web of Science, Crossref, Google Scholar, Scilit, Europe PMC.

Copyright: This is an open access article distributed under the Creative Commons Attribution License which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Article

Effect of Green Cowpea Manure on the Quality Properties of Sandy Soils under the Specific Conditions of the Dry Climate in Romania

Reta Draghici, Ștefan Nanu *, Aurelia Diaconu, Cristina Bîrsoghe, Florentina Netcu, Alina Nicoleta Paraschiv and Milica Dima

Research Development Station for Plant Culture on Sands Dăbuleni, 217, Petre Baniță Street, Dolj, Călărași 207170, Romania

* Correspondence: nanu.st@scdcpndabuleni.ro

Abstract: As a result of the low organic matter content of the sandy soils in Romania, for the success of most crops, large amounts of chemical fertilizers are needed, which can often lead to the pollution of groundwater with nitrates, given the poor hydrophysical properties in terms of retaining chemical elements by these soils. In this sense, the study carried out in the period 2020-2023 within the rotation cowpea-rye+cowpea successive crop-sorghum for grains, aimed to promote the system of sustainable agriculture, by incorporating into the soil, in the form of green manure, the cowpea sown in succession after the rye. The soil quality analyses, carried out the following year after harvesting sorghum for grains, showed that by incorporating 52.4 t/ha of cowpea biomass into the soil between October 15-20, the quality characteristics of the sandy soil improved significantly. Thus, compared to the initial state of soil fertility, there were annual increases of 0.017-0.029%, in total nitrogen, by 9.5-13.3 ppm, in extractable phosphorus, by 11.333-24 ppm, in exchangeable potassium and by 0.008-0.012%, to organic carbon, also depending on the sorghum fertilization system. Also, the incorporation of green cowpea manure into the soil contributed to reducing the acidity of the soil pH and improving the water holding capacity of the soil profile.

Keywords: cowpea; green cowpea manure; crop rotation; fertilization system; soil chemical quality; soil hydrophysical indices

1. Introduction

The deficient pedoclimatic conditions in areas with sandy soils, especially the reduced water retention capacity of the soil and recent global and regional climate changes, the decline of forests and anti-deflationary forest curtains, the strongly imprinted anthropic character of some significant surfaces, place these lands in the category of the most vulnerable to drought [1–3]. Given the forecast that agricultural production systems will need to produce food for a global population that could reach 9.1 billion by 2050 and more than 10 billion by the end of the century, we will need intelligent land use available [4]. The intensive use of sandy soils for agriculture leads to the significant degradation of land, so through intensive exploitation the reserves of nutrients have decreased, which makes their lack become the main limiting factor in obtaining high and stable productions [5]. Also, climate changes characterized by increased drought and lack of precipitation require orientation towards drought-resistant/tolerant crops, such as cowpea (*Vigna unguiculata* L. Walp), rye (*Secale cereale* L.) and grain sorghum (*Sorghum bicolor* L.), which they have a high adaptability to less favorable ecological conditions (poor soils, arid climate) [6–8]. Among the leguminous plants, the cowpea emerges as an alternative solution for drought conditions, its resistance being given by the rapid sprouting, the presence of the waxy layer on the leaves, high photosynthesis and the well-developed root system [9,10]. The existence in Romania of an area of approx. 439,000 ha with sands and sandy soils, of which 209,400 ha in Oltenia, soils with low natural fertility (below 1.2% humus) and deficient hydrophysical properties, implies finding solutions for efficient utilization of them [11–

13]. The introduction of leguminous plants in crop rotation is a measure to promote a sustainable agriculture, and the cowpea is the recommended plant for drought conditions, being tolerant at the same time to the deficiency of phosphorus and water in the soil [14] and brings benefits to the plants subsequent through the nitrogen it leaves in the soil at the end of the vegetation cycle [15,16]. The increase in soil organic carbon is an important factor in increasing soil fertility, because carbon is the key to all energy transformations in nature and directly influences all soil quality properties [17,18]. Soil organic matter includes plant and animal remains in various stages of decomposition, cells and tissues of soil organisms, plant root secretions, and soil microorganisms. Through the process of photosynthesis, carbon dioxide (CO₂) is transformed into plant material (the vegetative part and roots), and a part is sequestered in the soil in the form of organic carbon [19,20]. The use of green manure is a natural method of improving the chemical and physical properties of the soil, while also using crop rotation [21,22]. Also, the use of green manure is one of the environmental protection trends that help transition the agricultural sector to sustainability by conserving resources and meeting consumer demand for food [23]. Green manure, based on leguminous plants and crop rotation, by including leguminous plants in the rotation, contribute to the reduction of nitrogen doses applied to subsequent crops, as a result of the optimal use of nitrogen left in the soil, which they fix symbiotically with the help of bacteria of the genus *Rhizobium*, thus reducing the carbon footprint with the manufacture of synthetic nitrogenous chemical fertilizers [24–26]. Thus, studies carried out in South Africa have shown that cowpea, grown in an intercropping system with other plants (eg amaranth), can reduce the recommended dose of fertilizers by up to 50%, as a result of being fixed in the soil, with the help of bacteria symbiotic, of a significant amount of atmospheric nitrogen. [27]. Application of available organic residues (manure, zeolitic sedges and sugarcane stalks, etc.) can improve soil fertility, especially in the context of organic farming practices [28,29]. Studies conducted in India highlighted the beneficial role of green cowpea manure on mentholated mints, causing increases of 23.4% in fresh biomass yield and 25.2% in essential oil yield compared to variants without green manure [30]. In this cowpea-mint intercropping system, the contribution of green cowpea manure as a nitrogen source was equivalent to 30 kg N/ha when no nitrogen fertilizer was applied to mint. The results obtained in Romania, regarding the incorporation of cowpea biomass into the soil, highlighted the increase in the content of organic matter and nutritious chemical elements and the enrichment of the microbial flora of the soil [31]. The special role of green manure in protecting the soil against erosion, in improving it with organic matter and in improving some properties of the soil (holding capacity, permeability for water and air, as well as increasing soil reserves in easily assimilable elements) was highlighted [32]. Being a plant with low requirements for soil fertility, the cowpea is usually grown on the poorest sands, developing through the biology of the plant a rich vegetative mass, which incorporated into the soil in the form of green manure contributes to improving the physical and chemical properties of the sands, along with white lupine, peas and soybeans [33,34]. It was shown that against the background of improving the state of supply with organic matter, the green cowpea manure also favored the increase of the total cation exchange capacity and the state of supply of total and mineral nitrogen and accessible forms of phosphorus and potassium. As a result of the low organic matter content of sandy soils, which is closely dependent on the amount of organic residues and the activity of soil organisms, the success of most crops requires large amounts of chemical fertilizers, which can often lead to groundwater pollution with nitrates, taking into account the poor hydrophysical properties regarding the retention of chemical elements by sandy soils [32]. Therefore, finding solutions to preserve soil health is an essential measure, which is why the idea was developed in this study. National research has shown that the water content of sandy soils is outside the optimal limits characteristic of most plant species, representing a stress factor with major implications on the physiological processes in crop plants [35,36]. Drought has the effect of increasing the concentration of the soil solution, which causes a decrease in the water absorption capacity of the plants and a reduction in the turgor of the leaves. Decreased leaf water potential and turgor pressure affected the synthesis, transport and distribution of plant hormones such as ABA and cytokinin [37]. Thus, plants respond to water deficits through multiple physiological and metabolic adaptations at the molecular, cellular and organism level. To

withstand these conditions, plants tolerant to water stress acclimatize to the lack of water in the soil by synthesizing new proteins that retain water in cells, protect the structure of membranes, prevent the coagulation of cellular proteins under water stress conditions and maintain the structural integrity of cells. Therefore, under the conditions of a sustainable agriculture, alternative methods of increasing the fertility of sandy soils, of conserving water in the soil, in order to utilize them with good results by stress-tolerant agricultural plants, are being sought. The novelty of the research consists of studies on the implications of green cowpea manure, obtained in successive crops after rye, associated with fertilization with NPK macroelements, on the chemical and hydrophysical quality characteristics of the soil, in order to promote the sustainability of agriculture in the area of sandy soils in Romania.

2. Materials and Methods

2.1. Experimental Site

The research was carried out in the period 2020-2023 at the Research Development Station for Plant Culture on Sands Dăbuleni, located in the southwest of Oltenia, Romania (North latitude: 43° 48', East longitude: 24° 5'), having as aim to improve the chemical and hydrophysical quality characteristics of sandy soils, through the use of green bean manure, associated with fertilization with NPK macroelements, in order to promote the sustainability of agriculture on these qualitatively deficient lands. From a pedological point of view, the clay content of these soils is particularly low (0.7 - 3%), and the profile is dominated by coarse sand (78 - 88%) and fine sand (9 - 19%). These soils have a low apparent density at a depth of 1.0 m (1.42-1.52 g/cm³), which corresponds to a loose state of the soil and a medium-high total porosity [38]. From a hydrophysical point of view, the sandy soils in the south of Oltenia are characterized by low values of the wilting coefficient (1.1-2.1%) and field capacity (7.5-9.3%). The pH reaction of the soil remains weakly acidic towards neutral, and the humus content is generally below 1%. Due to the intense leaching process, the degree of supply of nitrogen, phosphorus and potassium is below the limit required by agricultural plants. From a climatic point of view, according to the *Köppen* climate classification [39], based on the natural distribution of plants native to an area, on annual and specific temperatures, on the rainfall regime, on local fluctuations and on seasonality, the area of psammosols in the south of Oltenia is included in the Cfa climatic province, having a pronounced temperate continental character, with a slight mediterranean influence, characterized by a pronounced dryness in the months of July - September and a surplus of precipitation in the months of May and June [40]. This lowland area has a climate with high annual thermal averages (11.67 °C), being in the area with the highest values in the country, but with low rainfall amounts (562.81 mm/year) and frequent droughts (Table 1).

Table 1. Climatic conditions recorded at the weather station* of SCDCPN Dăbuleni in the period 2020-2023, compared to the ultiannual average.

Climatic conditio ns	Calendar month												Period		
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Annual	I- VIII	VII-X
Average air temperat ure 2020- 2023 (°C)	2.0 6	4.4	6.4	11. 36	17. 6	21. 95	25. 18	25	19. 6	12. 93	7.2 5	3.3 5	13.0 9	22.4 3	20.6 8
Rainfall 2020-	60. 63	24. 15	51. 15	43. 4	58. 55	59. 7	44. 6	32. 93	38. 15	54	59. 7	45. 85	572. 81	195. 78	169. 68

2023, (mm)																
Multiannual average air temperat ure 2056- 2023 (0C)	- 1.2 6	1.1 9	5.8 7	11. 87	16. 95	21. 54	23. 32	22. 7	17. 99	11. 55	5.7 3	0.7 1	11.6 7	21.1 3	18.8 9	
Multiannual rainfall 2056- 2023, (mm)	36. 26	32. 41	40. 67	47. 13	62. 67	70. 01	54. 29	36. 55	44. 95	43	44. 78	49. 38	562. 10	223. 52	178. 79	
Deviation s of average air temperat ure, compare d to the multi- annual average (°C)	3.3 2	3.2 1	0.5 3	- 0.5 1	0.6 5	0.4 1	1.8 6	2.3	1.6 1	1.3 8	1.5 2	2.6 4	1.42	1.31	1.79	
Deviation s of average rainfall, compare d to the multi- annual average (mm)	24. 37	- 8.2 6	10. 48	- 3.7 3	- 4.1 2	- 10.31	- 9.6 9	- 3.6 2	-6.8	11	14. 92	- 3.5 3	79.3 8	- 27.7 4	- 9.11	

*AgroExpert - Adcon Telemetry SRL Romania.

2.2. Experimental Design

The study was carried out within the cowpea-rye+cowpea succession crop for green manure-sorghum for grains, with the aim of evaluating the implications of green cowpea manure and NPK chemical fertilization on the chemical and hydrophysical quality of the soil within this rotation. In this sense, annually between July 23-29, 2020-2022, after harvesting the rye crop, soil samples were

collected for fertility assessment. Then soil preparation works were carried out (ploughing + disking), and half of the plot was sown with the cowpea, in successive cultivation, being incorporated into the soil as green cowpea manure in the phase of the pod formation (15 - 22 October 2020-2022), when the maximum biomass production was recorded.

In the following years, i.e., in 2021, 2022 and 2023, as part of the rotation, grain sorghum was sown providing approx. 250,000 plants/ha in a bifactorial experiment, placed in the field according to the method of subdivided plots with two factors, in 3 repetitions. The factors studied were: factor A: Crop system (a1-without green cowpea manure; a2-with green cowpea manure) and factor B: Chemical fertilization in sorghum (b1- N80P80K80; b2- N150P80K80).

2.3. Analyzes and Experimental Determinations

a) Assessment of initial and final soil fertility. After harvesting the rye cultivated in the agricultural years 2019/2020, 2020/2021 and 2021/2022, soil samples were taken at the depths of 0-20 cm and 20-40 cm, in order to evaluate the initial state of soil fertility, respectively the content of the soil in total nitrogen (N_{total} , %), mobile phosphorus (P-AL, ppm), mobile potassium (K-AL, ppm*), organic carbon (C_{org} %) and soil reaction pH in water ($\text{pH}_{\text{H}_2\text{O}}$). The same determinations were made after harvesting sorghum, the plant that followed in the rotation after rye or rye+green cowpea manure.

*ppm = parts per million (mg/kg)

The soil samples were recorded and conditioned in the laboratory, using standard methods for determining soil fertility [41–43]:

- N_{total} was determined by the Kjeldahl method;
- P-AL was determined by the Egner–Riem Domingo method, in which phosphates are extracted from the soil sample with an ammonium acetate–lactate solution at pH=5.75, and the extracted phosphate anion is determined colorimetrically in the form of blue molybdenum;
- K-AL was determined with the Egner–Riem Domingo method, by which the hydrogen and ammonium ions of the extraction solution replace potassium ions in exchangeable form from the soil sample, which are thus passed into the solution. The dosage of potassium in the solution thus obtained is done by flame emission photometry;
- C_{org} was determined by the method of wet oxidation and titrimetric dosing (according to Walkley – Blak in the Gogoșă modification);
- The pH was determined by the potentiometric method.

b) Determinations of cowpea biomass incorporated into the soil

After harvesting the rye, every year from 2020-2022 the cowpea variety *Aura 26* was sown, at a distance of 25 cm between the rows, ensuring approx. 55 plants/m². In order to evaluate the maximum amount of biomass, observations and determinations of growth and development of the cowpea plant were carried out (number of plants emerged, vegetation period, plant height, number of shoots per plant, biomass production in the flowering phase and in the pod formation phase). In the flowering phase of the plant, the number of nodules/root and the leaf surface index were determined (no. plants/m² × no. leaves/plant × leaf surface). Leaf surface area was determined in the laboratory using the *AM 300* device as follows: the surface area of each of the 3 leaflets that make up the cowpea leaf was determined and the measurements were summed. For the measurements, the leaves formed at half the height of the plant were chosen.

c) Determinations regarding soil hydrophysical indices.

In the phase of maximum water consumption of the sorghum plant (phase of grain formation in the panicle), soil samples were collected at 3 depths (H) 0-20 cm, 20-40 cm and 40-60 cm and determined soil moisture (W%) through readings directly in the field using the *ThetaKit* device - portable kit with accessories. 5 days before the collection of soil samples, the climatic conditions were monitored daily, respectively: average air temperature (°C), rainfall (mm), relative air humidity (%). Depending on soil moisture, soil hydrophysical indices were calculated, respectively: provision momentary water (PMW, m³/ha), water corresponding to the withering coefficient (WC, m³/ha), water corresponding to the field capacity for water (FCW, m³/ha), minimum water ceiling la sorg

(MWC, m³/ha), water reserve $\hat{w}$ (WR, m³/ha), water deficit (WD m³/ha), which is actually the watering norm (WN, m³/ha), according to the specialized literature [44–46], using the formulas:

- PMW(m³/ha) =(100xHxDaxW)
- (1) WC(m³/ha) = 100xHxDaxWCsp
 - (2) FCW (m³/ha) =100xHxDaxFCWsp
 - (3) MWC(m³/ha) = WC+1/2(FCW- WC)
 - (4) WR (m³/ha) = PMW - MWC
 - (5) WD (m³/ha) = PMW – FCW
 - (6) WN (m³/ha)= H x Da x (FCWsp-W) x 100

where:
H = soil depth (m)
W = soil moisture (%)
Da = the apparent density of the soil, depending on the depth of the soil sample, as follows: 0-20 cm = 1.38 g/cm³; 20-40 cm = 1.40 g/cm³; 40-60 cm = 1.42 g/cm³
WCsp=Withering coefficient specific to sandy soils = 2%
FCWsp= Specific water field capacity of sandy soil =9%

2.4. Statistical Analysis

The calculation and analysis of the obtained research results were carried out using the analysis of variance (ANOVA) program at the significance level of 5%, 1% and 0.1% and mathematical functions.

3. Results

3.1. Relationship of Cowpea and Sorghum Plants to Climatic Conditions

Climatological analysis from July to October (Table 1), the vegetation period of cowpea for biomass, revealed optimal temperatures for the plant’s biology, with average values of 20.68 °C, which exceeded the multiannual average by 1.79 °C, being favorable to the growth and development of cowpea plants sown in succession, considering that the specialized literature mentions that from germination to the end of the vegetation period, all the vital processes of the bean plant take place in high temperature conditions, above 10⁰ C. The rainfall regime, of 169.68 mm, was below the multi-year average, being deficient for the growth and development of the cowpea plant, it being necessary to supplement the soil moisture through the irrigation work (2-3 waterings with a watering rate of 250 m³ water/ ha). For the grain sorghum crop, the climatic conditions recorded during the vegetation period (May-August) highlighted the increase in the drought phenomenon by increasing the air temperature by 1.31 °C, compared to the multi-annual average, which corroborated with the recorded precipitation, which -they were 27.74 mm below the multi-year average level, they led to an increase in thermohydric stress in the area of sandy soils, and sprinkler irrigation was also applied to ensure the plant’s water needs.

3.2. Features of Green Cowpea Manure

The experimental results obtained showed a good behavior of the cowpea variety *Aura 26* in successive culture (Table 2). Thus, by sowing between July 23-29, after harvesting the rye plant, the cowpea plants registered a uniform emergence after 5-7 days from sowing. Determinations of cowpea plant biometry, carried out at the time of incorporation into the soil as green manure, revealed an average height of 94 cm, with 2.2 shoots/plant, 110.7 nodules/plant and a leaf area index of 12.5. Biomass production recorded a maximum of 52.4 t/ha when the cowpea plant was in the pod formation phase, after 70-85 days from emergence which coincided with the calendar period of October 15-22.

Table 2. Biological and morphological characteristics of the cowpeavariety *Aura 26*, sown in succession after rye.

Characteristics		2020	2021	2022	Average
Date of sowing		July 23	July 29	July 26	July 23-29
Plant emergence date		July 28	August 6	August 2	July 28 - August 6
The date of formation of the grains in the pod		October 20	October 15	October 22	October 15-22
No plante/m ²		55	55	55	55
Plant height (cm)		91.6	88.3	102	94
No. shoots/plant		2.2	1.2	3.1	2.2
No. nodules / root		116	95	121	110.7
Leaf area index		11.7	12.7	13.2	12.5
Biomass weight t/ha	in the flowering phase	35.5	31	38.6	35.0
	in the phase of grain formation	56.4	42.4	58.5	52.4
	in pods				

3.3. Soil Chemical Quality Analysis

The statistical analysis of the evolution of some agrochemical indices of the soil, recorded after the harvest of sorghum, compared to the initial fertility determined after the harvest of the preceding rye plant, revealed the improvement of the soil content in total nitrogen, mobile phosphorus, mobile potassium and organic carbon, both on the depth of 0-20 cm and on the depth of 20-40 cm, under the influence of green cowpea manure and chemical fertilization with macroelements (Table 3). Thus, the highest values of the content of total nitrogen, phosphorus and mobile potassium, as well as organic carbon, were recorded in the variant in which 52.4 t/ha of cowpea biomass was incorporated into the soil in the form of green manure + chemical fertilization with N150P80K80, the increases being statistically ensured, compared to the initial content of chemical elements for total nitrogen (0.028-0.031%), mobile phosphorus (9.33-17.333 ppm) and mobile potassium (19.333-28.667 ppm). Organic carbon values also increased by 0.11-0.13%, but the difference from the initial content was insignificant. Soil pH determinations, carried out immediately after harvesting the rye, revealed a moderately acid to neutral reaction (pH= 6.563-6.913). Unilateral fertilization with chemical fertilizers with NPK, especially with increased doses of nitrogen, determined soil acidification, by recording in the 0-40 cm soil profile a pH lower by 0.130-147 units, the difference being insignificant. The use of green cowpea manure determined the improvement of soil pH, by increases of 0.010-0.054 units, on the depth of 0-20 cm and by 0.157-0.172, on the depth of 20-40 cm, the increases being not statistically assured (Table 3).

Table 3. Evolution of chemical quality indices on the soil profile under the grain sorghum crop placed in different fertilization systems (2020-2023).

Soil depth (A)	Culture system (B)				N _{total} (%)	P-AL (ppm)	K-AL (ppm)	C _{org} (%)	pH _{H2O}
0-20 cm	Initial	soil	fertility	status	0.064	52.333	67.000	0.592	6.913
	(Control)	No green cowpea manure + N80P80K80			0.066	55.333	66.667	0.597	6.877

	No green cowpea manure + N150P80K80	0.073	57.333	72.333	0.599	6.783
	With green cowpea manure + N80P80K80	0.081**	64.667**	79.000	0.601	6.967
	With green cowpea manure + N150P80K80	0.092***	69.667***	95.667***	0.605	6.923
	<i>Average depth 0-20 cm (Control)</i>	0,075	59.867	76.133	0.599	6.893
	Initial soil fertility status (Control)	0.051	61.667	77.333	0.422	6.563
	No green cowpea manure + N80P80K80	0.051	62.333	78.333	0.424	6.487
20-40 cm	No green cowpea manure + N150P80K80	0.061*	67.667	86.333	0.425	6.417
	With green cowpea manure + N80P80K80	0.069**	68.333	88.000	0.429	6.737
	With green cowpea manure + N150P80K80	0.082***	71.000*	96.667**	0.433	6.720
	<i>Average depth 20-40 cm</i>	0,063 ⁰⁰	66.200	85.333	0.427 ⁰	6.585
A	LSD 5%	0.005	13.976	43.770	0.121	0.523
	LSD 1%	0.011	32.275	101.078	0.280	1.206
	LSD 0,1%	0.035	102.709	321.658	0.892	3.846
A x B	LSD 5%	0.010	7.964	12.658	0.028	0.199
	LSD 1%	0.014	10.969	17.435	0.038	0.274
	LSD 0,1%	0.019	15.101	24.002	0.053	0.378

***/⁰⁰⁰ – significant positive /negative for P>0.01; **/⁰⁰ - significant positive /negative P>0.1; */⁰ - significant positive /negative for P>0.5.

Analyzing the influence of the cropping system on soil quality, the best results were recorded by combining organic fertilization in the form of green cowpea manure with chemical fertilization (Table 4). In these fertilization options, very significant annual increases were noted in the total nitrogen in the soil, respectively 0.017-0.029%, distinctly and very significant in extractable phosphorus, respectively 9.5-13.333 ppm and in exchangeable potassium, respectively 11.333 -24 ppm and insignificant for organic carbon, of 0.008-0.012%, depending on the chemical fertilization system of sorghum (Table 4). Also, the incorporation of green cowpea manure into the soil contributed to the reduction of soil pH acidity by increases of 0.083-0.113 units, compared to the initial value of 6.738.

Table 4. Evolution of soil quality indices, compared to the initial state of soil fertility, depending on the grain sorghum cropping system (2020-2023).

Culture system	N _{total} (%)	P-AL	K-AL	C _{org}	pH _{H2O}
		(ppm)	(ppm)	(%)	
Initial soil fertility status (Control)	0.058	57.000	72.167	0.507	6.738
No green cowpea manure + N80P80K80	0.059	58.833	72.5	0.510	6.682

No green cowpea manure + N150P80K80	0.067*	62.5**	79.333	0.512	6.600
With green cowpea manure + N80P80K80	0.075***	66.5***	83.500*	0.515	6.852
With green cowpea manure+ N150P80K80	0.087***	70.333**	96.167***	0.519	6.822
LSD 5%	0.007	5.631	8.951	0.020	0.141
LSD 1%	0.010	7.756	12.328	0.027	0.194
LSD 0.1%	0.014	10.678	16.972	0.037	0.267

***/000 – significant positive /negative for P>0.01; **/00 – significant positive /negative P>0.1; */0 – significant positive /negative for P>0.5.

The increase in soil organic carbon was positively correlated with the content of total nitrogen, extractable phosphorus, exchangeable potassium and pH_{H2O}. The correlations are represented graphically with the help of polynomial functions, and the values of the coefficients of determination (R²) and the correlation coefficients (r²) underlined a close connection between the organic matter in the soil and the content in macroelements, both on the soil profile 0-20 cm, as well as on the soil profile 20-40 cm. The analysis of the soil quality on the 0-20 cm soil profile (Figure 1) highlighted the existence of some statistically significant correlations between the values of organic carbon in the soil and the values of total nitrogen (r=0.985**), extractable phosphorus (r=0.975**) and exchangeable potassium (r=0.997**) and insignificant with pH (r=0.461). The results recorded on the 20-40 cm soil profile show the same trend of evolution of the content of macroelements and pH_{H2O}, in relation to the values of organic carbon in the soil (Figure 2).

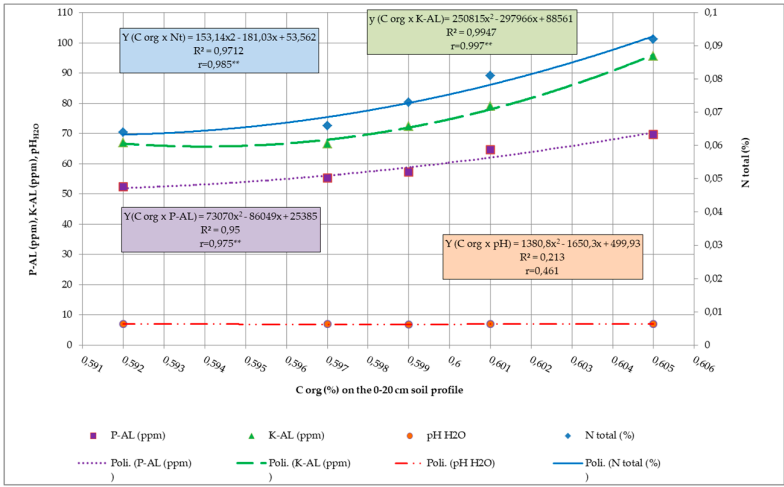


Figure 1. Significance of the interaction between organic carbon and N,P,K and pH values recorded at 0-20 cm depth on the sandy soil profile.

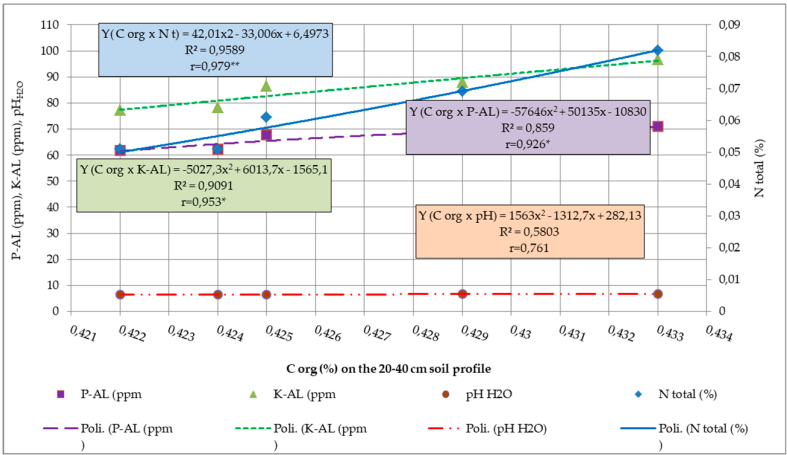


Figure 2. Significance of the interaction between organic carbon and N,P,K and pH values recorded at 20-40 cm depth on the sandy soil profile.

3.4. Analysis of Soil Hydrophysical Indices under Grain Sorghum Culture in the Phase of Maximum Water Consumption

Analyzing the climatic conditions recorded in the period 2021-2023 (Table 5), for a period of 5 days before the collection of soil moisture samples, high values of the average temperature in the air were highlighted, which corroborated with a deficient regime of precipitation and a low relative humidity in the air led to the accentuation of the drought phenomenon during the grain formation phase in the panicle of the sorghum crop, which was sown in rotation after rye sorghum, a phase in which the plant’s consumption of water is maximum. Under these conditions, soil moisture was differentiated on the soil profile, depending on the cropping system (without/with green cowpea manure incorporated into the soil) and chemical fertilization with NPK (Table 6). Thus, in the phase of grain formation in the panicle, the soil moisture was differentiated according to the depth of the soil and the culture system, registering very low values with limits in 2.47-3.97%, on the depth of 0-20 cm, between 3.23-4.77% at the depth of 20-40 cm and in 3.70-5.63% at the depth of 40-60 cm. A trend of increasing moisture on the soil profile was noted, with water being best conserved at a depth of 40-60 cm, while the lowest values were recorded in the surface layer of the soil (0-20 cm), which it was more exposed to water losses, both through runoff on the profile and through evaporation. The use of green cowpea manure caused a better water retention in the soil, compared to the control without green manure, so the moisture in the soil profile 0-60 cm increased by 1.22-1.62%, the increases being significant from statistical point of view on the depths 20-40 cm and 40-60 cm. The use of moderate doses of chemical fertilizers (N80P80K80), on an agrofund of green cowpea manure incorporated into the soil, contributed to a better conservation of water in the soil, the average moisture in the 0-60 cm soil profile being 4.79 %.

Table 5. Climatic conditions recorded for a period of 5 days before the collection of soil moisture samples (2021-2023).

Average air temperature (°C)	Rainfall (mm)	Average relative air humidity (%)
26.26-28.3	0-4	44.8-54.5

Table 6. Evolution of soil moisture at the depth of 0-60 cm under the sorghum culture during the phase of grain formation in the panicle (2021-2023).

The experimental variant	Soil moisture (W%)
--------------------------	--------------------

Culture system	Chemical fertilization	0-20 cm	20-40 cm	40-60 cm	Average W%
a1. No green cowpea manure	b1. N80P80K80 (control)	2.80	3.30	4.07	3.39
	b2. N150P80K80	2.47 ⁰	3.23	3.70 ⁰	3.14
	Average a1	2,63	3.27	3.88	3.26
a2. With green cowpea manure	b1. N80P80K80 (control)	3.97	4.77	5.63	4.79
	b2. N150P80K80	3.73	4.43	5.37	4.51
	Average a2	3,85	4.60*	5.5*	4.65*
The significance of A	LSD 5%	1.8	0.73	0.86	1.04
	LSD 1%	4.15	1.69	1.99	2.40
	LSD 0.1%	13.2	5.39	6.34	7.65
The significance of A x B	LSD 5%	0.29	0.59	0.35	0.44
	LSD 1%	0.48	0.97	0.58	0.72
	LSD 0.1%	0.91	1.82	1.09	1.35

***/⁰⁰⁰ – significant positive /negative for P>0.01; **/⁰⁰ - significant positive /negative P>0.1; */⁰ - significant positive /negative for P>0.5.

The calculation of soil hydrophysical indices (Table 7), according to the average moisture calculated on the soil profile 0-60 cm, revealed a lower soil water reserve by 59.64-198.24 m³/ha, compared to the minimum ceiling for water of the sandy soil of 462 m³/ha. Under these conditions, during the phase of grain formation in the panicle, a water deficit was recorded in the soil between - 492.24... and -353.64 m³/ha, a deficit that must be ensured by watering norms between 353.64-492.24 m³/ha. The highest water reserve in the soil and, implicitly, the lowest water deficit was recorded in the variant fertilized with N80P80K80, in a sorghum cultivation system on a land where green cowpea manure was incorporated into the soil in the autumn of the previous year, the watering norm to be applied being the lowest. By growing sorghum for grains in a culture system with green cowpea manure, incorporated into the soil in the fall of the previous year, the watering norm applied during the grain formation phase in the panicle is reduced by 116.34 m³ water/ha.

Table 7. Hydrophysical indices of the sandy soil recorded during the maximum consumption phase of the grain sorghum plant, depending on the cropping system and applied fertilization.

The experimental variant											
Cultu re syste m	Chemical fertilizati on	H (m)	W (%)	Da (g/cm ³)	PMW (m³/h a)	WC (m³/h a)	FCW (m³/h a)	MW C (m³/h a)	WR (m³/h a)	WD (m³/h a)	WN (m³/h a)
No green cowp ea manu re	N80P80K80	0.6	3.39	1.4	284.7 6	168	756	462	- 4	- 4	471,2 4
	N150P80K80	0.6	3.14	1.4	263.7 6	168	756	462	- 4	- 4	492,2 4

Average		0,6	3.26 5	1.4	274.2 6	168	756	462	- 187.7 4	- 481.7 4	481.7 4
With green cowp ea manu re	N80P80K 80	0.6	4.79	1.4	402.3 6	168	756	462	-59.64	353.6 4	353,6 4
	N150P80 K80	0.6	4.51	1.4	378.8 4	168	756	462	-83.16	377.1 6	377,1 6
	Average	0,6	4.65	1.4	390.6	168	756	462	-71.4	-365.4	365.4

The analysis of the functional link between soil organic carbon and soil moisture, recorded at the depths of 0-20 cm and 20-40 cm (Figure 3 a, b), revealed positive correlations, which reveal the increase in soil moisture with the increase in the percentage of organic carbon , the interaction being tighter on the 20-40 cm soil profile, the correlation coefficient (r=0.953*), being statistically assured as significant.

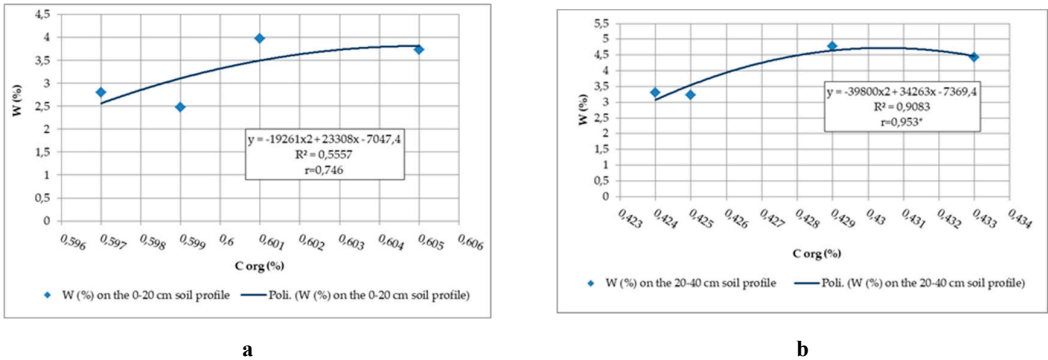


Figure 3. a,b. Correlations between organic carbon content and soil moisture recorded at 0-20 cm (a) and 20-40 cm (b) depths.

4. Discussion

The reduced fertility of sandy soils and the expansion of arid areas with visible accents of desertification was the idea that I developed in this work, in order to orientate towards new concepts in the effective utilization of sandy soils, soils with a low natural fertility, which would be included in a sustainable agriculture system. In this sense, the effect of green cowpea manure on the chemical and hydrophysical quality properties of the sandy soil was studied. The cowpea is one of the leguminous plants that behaves very well in conditions of thermohydric stress, being successfully cultivated in crop rotations in dry areas [47–49].The increase of 1.79 0C in the average temperature from July to October, compared to the multi-year average (Table 1, Table 2) can allow the sowing of cowpea in the successive crop after the harvest of the straw grains (rye) for green manure or even for obtaining pods green [50]. The drought tolerance of the cowpea was highlighted by research carried out at the University of Arkansas on some bean lines subjected to thermohydric stress in greenhouse conditions, pointing out that many of them survived more than 40 days in excessive drought conditions [51]. Intraspecific competition between plants, which takes place during the development of the leaf system and the root system of the cowpea plant, has demonstrated that greater increases in energy biomass can be achieved as the plant is grown in an area as similar as possible to that of origin [52,53], Romania offering such an area in the south of Oltenia, named “Sahara Olteana”.

The results obtained in our study showed an increase of 9.33-17.333 ppm in the content of mobile phosphorus in the soil under the influence of incorporating into the soil 52.4 t/ha of cowpea biomass in the form of green manure + chemical fertilization with N150P80K80 (Table 3), results that are also confirmed by research carried out in Spain [54]. This research which highlighted the positive effect of cowpea crop, introduced in crop rotations with broccoli, on soil fertility, by increasing the content of available phosphorus in the soil after three crop rotations, by 30-120%, depending on fertilization, compared with the practice of monoculture.

Also, green manure and a balanced fertilization according to the requirements of the sorghum plant, had the effect of increasing the content of N_{total} , P-Al, K-Al, results confirmed by and other authors, who showed that the incorporation of green manure into the soil improves soil total N, P_2O_5 and K_2O and also the mineralizable N content [55]. Results obtained in India on the use of green manures with different plants including cowpea (*Vigna sinensis* and *Vigna radiata*) have highlighted their potential to improve the physical, chemical and biological characteristics of soil, ultimately leading to improved crop yields in crops further [56], confirming the result obtained in this study, whereby green cowpea manure improved the content of organic matter and nutritive elements in the soil, which can be made available to plants in the rotation. The research carried out in this experiment highlighted the positive effect of green bean fertilizer on the organic carbon content of the soil through the annual accumulation of 0.008-0.012% organic carbon (Table 4), results that are confirmed by data from the specialized literature, which showed that with the application of low and high levels of green manure, the content of active organic carbon and the content of inert organic carbon in the soil increased significantly with or without the application of P fertilizer [57]. Also the research carried out in a doctoral thesis by Ion P. (1991), cited by [7], it shows that after three years of the annual incorporation of bean biomass into sandy soil, an organic carbon accumulation of 0.034% was recorded in the soil layer 0-20 cm, compared to the control without green manure, where 0.009% accumulated. These accumulations of organic matter are small mainly due to the low isohumic coefficient of sandy soils, of 8%. The cowpea, used as a green fertilizer, brings nutrients from the deeper horizons into the arable horizon with the help of the roots and at the same time contributes to increasing the efficiency of mineral fertilizers with N, P, K, the processes of washing nutrients in sandy soils being very decreased due to biological retention by the plant used as green manure [58]. The research carried out at the NARDI Fundulea, in Romania, highlighted that the decrease in the organic substance content of the soil through cultivation with plants, showing that the percentage of organic carbon increases proportionally with the dose of nitrogen fertilizer applied to the plants, results that were also confirmed in the experiment of in which the increase of the nitrogen dose to 150 kg/ha determined the increase of organic carbon in the soil by 0.002-0.004% compared to the use of the dose of 80 kg/ha nitrogen, on the same agrofund of phosphorus and potassium [59]. Also results obtained in Brazil showed that the use of green bean fertilizer caused a significant increase in the content of exchangeable cations in the soil (K, Mg, Ca) under the Cassava crop [60]. Soil reaction was another quality indicator that improved under the influence of green bean manure and moderate NPK fertilization. The increase in the nitrogen dose to N150 determined the three-year average reduction of the soil pH by 0.138 units (Table 4), sandy soils being exposed to acidification, as a result of the application of increased nitrogen doses year after year to increase productions in cultivated plants. Similar results were obtained in Central China, Henan province where cultivated land faces the risk of accelerating soil acidification due to continuous excessive nitrogen application, increasing the removal of base cations, while promoting crop yield and decreasing or even disappearing carbonate material from the soil, and under these conditions of intensive agriculture the soil pH was reduced by 0.36 units over a period of 10 years [61]. Our research revealed positive correlations, assured as significant and distinctly significant, between soil organic carbon with total nitrogen, extractable phosphorus and exchangeable potassium, and positive but non-significant correlations between organic carbon and soil pH_{H_2O} , with interactions stronger in the soil profile 0-20 cm (Figure 1, Figure 2). A similar relationship, was highlighted by the results obtained in Poland with the difference that the values of the correlation coefficients revealed tighter links between organic carbon with nitrogen and pH and weaker correlations between organic carbon with phosphorus and mobile

potassium [19]. In the scenario of global climate change, drought is considered one of the abiotic stress factors affecting plant growth and development, food security, and causing the greatest crop losses [52,62]. Therefore, the efficient use of water by plants is becoming increasingly important in arid and semi-arid regions with limited water resources. In order to establish water consumption, the irrigation regime and the moment of application of watering, many factors must be taken into account regarding the relationships and interrelationships between soil, plant and water in certain given environmental conditions [63]. In this sense, the results presented in tables 6 and 7 underline the implications of green cowpea manure and a rational NPK fertilization on increasing the capacity of sandy soil to conserve soil moisture and this positively correlating with the increase of organic matter in the soil (Figure 3, a, b), which leads to reduced water deficit and increased water use efficiency by the grain sorghum plant. Soil water content outside the optimal limits characteristic for a species is a stress factor with major implications on physiological processes in crop plants. Although sorghum is a drought-tolerant crop, in conditions of heat and prolonged drought the plant reacts with significant production losses. Water stress at the vegetative growth stage can reduce production by more than 36%, and water stress at the reproductive stage (panicle emergence-grain formation phase) can reduce production by more than 55% [64]. In this direction, it will be necessary to expand the research on the evolution of soil moisture and implicitly the hydrophysical indices of the soil throughout the growing season of sorghum cultivated in different cropping systems, so as to correlate water consumption with the degree of plant development. Also a future problem is the efficiency of nitrogen use applied by the sorghum plant, by calculating the nitrogen exported with the main production (grain production) and the secondary one (vegetable residues), in order to achieve a management of fertilizers as friendly as possible to the environment.

5. Conclusions

The incorporation into the soil of 52.4 t/ha of green cowpea manure, associated with NPK fertilization, determined the improvement of soil quality by recording annual increases in total nitrogen by 0.017-0.029%, extractable phosphorus by 9.5-13.3 ppm, exchangeable potassium with 11.333-24 ppm and organic carbon with 0.008-0.012%, depending on the sorghum fertilization system. Also, the incorporation of green cowpea manure into the soil contributed to the reduction of soil pH_{H2O} acidity, by increases of 0.083-0.113 pH units and to the improvement of the water retention capacity of the soil profile, so that the watering norm, from the phase of grain formation in the sorghum panicle, was reduced by 116.34 m³ water/ha.

Author Contributions: Conceptualization, R.D., Ș.N. and C.B.; methodology, R.D., C.B, A.N.P. software, R.D., A.N.P.; validation, M.D., F.N. and A.N.P.; formal analysis, A.N.P, F.N., A.D.; investigation, R.D., F.N., A.D.; data curation, A.D., M.D, F.N.; writing—original draft preparation, R.D., Ș.N., M.D.; writing—review and editing, R.D., Ș.N. C.B.; visualization, A.D., M.D.; supervision, Ș.N., C.B.; project administration, R.D. All authors have read and agreed to the published version of the manuscript.

Funding: This work was supported by Ministry of Agriculture and Rural Development (Program ADER 2022, Contract no. 1.4.2 /27.09.2019): State budget, (Project 1740/2018, by HG 837/22.11.2017).

Data Availability Statement: The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

Conflicts of Interest: The authors declare that they have no conflict of

References

1. José Miguel Reichert, Telmo Jorge Carneiro Amado, Dalvan José Reinert, Miriam Fernanda Rodrigues, Luis Eduardo Akiyoshi Sanches Suzuki, 2016. Land use effects on subtropical, sandy soil under sandization/desertification processes. *Agriculture Ecosystems & Environment*, Volume 233, 3 October 2016, Pages 370-380. <https://doi.org/10.1016/j.agee.2016.09.039>
2. Anca Luiza Stanila, Catalin Cristian Simota, Iulian Ratoi, Aurelia Diaconu, Mihail Dumitru, 2019. Research on Improving Fertility Sandy Soils from Dabuleni Field by Administration of Loess. *Revista de Chimie (Rev. Chim.)*, Year 2019, Volume 70, Issue 2, 543-548. <https://doi.org/10.37358/RC.19.2.6952..>

3. Orhan Dengiz, İnci Demirağ Turan, 2023. Soil quality assessment for desertification based on multi-indicators with the best-worst method in a semi-arid ecosystem. *Journal of Arid Land* Volume 15, pages 779–796. Electronic ISSN 2194-7783; Print ISSN: 1674-6767. <https://doi.org/10.1007/s40333-023-0020-9>.
4. P. Schröder, B. Beckers, S. Daniels, F. Gnädinger, E. Maestri, N. Marmiroli, M. Menc, R. Millan, M. Obermeier, N. Oustriere, T. Persson, C. Poschenrieder, F. Rineau, B. Rutkowska, T. Schmid, W. Szulc, N. Witters, A. Sæb., 2018. Intensify production, transform biomass to energy and novel goods and protect soils in Europe-A vision how to mobilize marginal lands. *Science of The Total Environment*, Volumes 616–617, March 2018, Pages 1101-1123 <https://doi.org/10.1016/j.scitotenv.2017.10.209>.
5. Croitoru Mihaela, Gheorghe D., 2003. The evolution of some soil fertility indicators following the application of chemical fertilizers to grain sorghum on the sandy soils of southern Oltenia. *SCDCPN Dăbuleni Scientific Papers*, vol XIV. Ed Sitech, ISBN: 973-657-514-4, pp. 79-89, https://www.scdcpndabuleni.ro/wp-content/uploads/Lucrari-stiintifice-SCDCPN-Dabuleni-Vol_XIV.pdf
6. Drăghici Iulian, Drăghici Reta, Croitoru Mihaela, Diaconu Aurelia, Băjenaru Maria Florentina, Dima Milica, 2020. Studies on the implications of fertilization and plant nutrition space on grain sorghum production components in sandy soil conditions. *Annals of the University of Craiova, Series: Biology, Horticulture, Food products processing technology, Environmental engineering*, Vol. XXV (LXI)-2020, pag. 340-345, I.S.S.N. 1453 – 1275 I.S.S.N. 2393 – 1426 (on line), https://horticultura.ucv.ro/horticultura/sites/default/files/horticultura/Reviste/Analele/2021/10_63-68_Draghici%201_Anale%20Horti%202021.pdf.
7. Reta Drăghici, Georgeta Ciurescu, Gheorghe Matei, Aurelia Diaconu, Ștefan Nanu, Mirela Paraschiv, Iulian Drăghici, Alina Paraschiv, Mihaela Croitoru, Milica Dima, Maria Băjenaru, Florentina Netcu, Daniela Ilie, 2022. Restoring the production capacity and protection of agroecosystems in the area of sandy soils by promoting in culture some species of plants tolerant to thermohydric stress, rye, sorghum, cowpea. ISBN 978-606-11-8228-2, 254 pagini, Editura SITECH, Craiova, <https://www.scdcpndabuleni.ro/wp-content/uploads/Refacerea-capacitatii-de-productie-si-protectie-a-agroecosistemelor-din-zona-solurilor-nisipoase-prin-promovarea-in-cultura-a-unor-specii-de-plante-tolerante-la-str.pdf>.
8. Mirela Paraschiv, Gheorghe Matei, Otilia Cotuna, Marius Paraschiv, Reta Drăghici, 2022. Management of pests and pathogens in rye crop in dry marginal environment in southern Romania. *Scientific Papers. Series A. Agronomy*, Vol. LXV, No. 1, 2022 ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785 pag. 466-474, . https://agronomyjournal.usamv.ro/pdf/2022/issue_1/Art68.pdf
9. Grace Adusei, Moses Kwame Aidoo, Amit Kumar Srivastava, James Yaw Asibuo, Thomas Gaiser, 2022. The impact of climate change on the productivity of cowpea (*Vigna unguiculata*) under three different socio-economic pathways. *Italian Journal of Agronomy*, 17(4). <https://doi.org/10.4081/ija.2022.2118>.
10. Nunes C., Moreira R., Pais I., Semedo J., Simões F., Veloso M.M., Scotti-Campos P., 2022. Cowpea physiological responses to terminal drought-comparison between four landraces and a commercial variety. *Plants*, ISSN: 2223-7747, 11(5), 593; <https://doi.org/10.3390/plants11050593>.
11. Daniel SIMULESCU , Andreea ZAMFIR, 2015. Dynamics of land use changes in Dăbuleni plain (southwestern Romania). *Annals of Valahia University of Târgoviște. Geographical Series* 15.2 (2015): 77-84, https://www.researchgate.net/publication/295859232_Dynamics_of_land_use_changes_in_Dabuleni_Plain_Southwestern_Romania.
12. Mihai PARICHI, Anca-Luiza STĂNILĂ, Ștefan ISPAS, 2012. Changes in the pedolandscape of the Romanăți Plain (The Field of Dăbuleni). *Scientific Papers. Series A. Agronomy*, Vol. LV-2012, ISSN Online 2285-5793; ISSN-L 2285-5785. <https://agronomyjournal.usamv.ro/pdf/vol55/Art16.pdf>.
13. Cotet G., Diaconu A., Nanu S., Paraschiv N. A., Dima M., Mitrea R. 2023. Research on the behavior of some sweet potato genotypes cultivated on the sandy soils of southern Romania. *Scientific papers-series b-horticulture*, Volume 67 Issue 1 Page 566-571, ISSN 2285-5653, https://horticulturejournal.usamv.ro/pdf/2023/issue_1/Art75.pdf.
14. Grace Adusei., Moses Kwame Aidoo, Amit Kumar Srivastava, James Yaw Asibuo, Thomas Gaiser, 2021. The variability of grain yield of some cowpea genotypes in response to phosphorus and water stress under field conditions. *Agronomy* 11(1):28. <https://doi.org/10.3390/agronomy11010028>.
15. Sinclair T.R., Manandhar A., Ouhoun B., Riar M., Vadez V., Roberts P.A., 2015. Variation among cowpea genotypes in sensitivity of transpiration rate and symbiotic nitrogen. Fixation to soil drying. *Crop Science Society of America*, Springer, New York, 55(5): 2270-2275.
16. Sánchez-Navarro V., Zornoza R., Faz Á., Fernández J. A., 2021. Cowpea crop response to mineral and organic fertilization in S E Spain. *Processes*, 2021, 9 (5), 822; <https://doi.org/10.3390/pr9050822>.
17. Lucian Ghinea, Gheorghe Ștefanic, Ana Popescu, Georgeta Oprea, 2007. Research in the field of soil chemistry and biology. *Chemistry, Biochemistry, Physiology. Annals N.A.R.D.I. FUNDULEA*, VOL. LXXV, 2007, VOLUM JUBILIAR, p 404-429, . <https://www.incda-fundulea.ro/anale/75/75.22.pdf>
18. Moraru P.I., Rusu T., Soptorean M.L., 2010. Tillage control and its effect on erosion. Water management and carbon sequestration. *Pro Environment* 3 (2010) 541 – 548,

- https://www.researchgate.net/publication/49607211_Soil_Tillage_Conservation_and_its_Effect_on_Erosion_Control_Water_Management_and_Carbon_Sequestration.
19. Tomasz Dudek, Paweł Wolański, Krzysztof Rogut, 2020. Accumulation of organic carbon in soil under various types of highland temperate meadows. *Journal of Elementology* 25(1):85-96 <https://doi.org/10.5601/jelem.2019.24.2.1849>.
 20. Wenmin Zhang, Guy Schurgers, Josep Peñuelas, Rasmus Fensholt, Hui Yang, Jing Tang, Xiaowei Tong, Philippe Ciais & Martin Brandt, 2023. Recent decrease of the impact of tropical temperature on the carbon cycle linked to increased precipitation. *Nature communication* 14, Article number: 965 .Article <https://doi.org/10.1038/s41467-023-36727-2>.
 21. Xiaoye Gao, Yan He, Yan Chen, Yu Chen, Ming Wang, 2024. Leguminous green manure amendments improve maize yield by increasing N and P fertilizer use efficiency in yellow soil of the Yunnan-Guizhou Plateau. *Frontiers in Sustainable Food Systems*, 09 February 2024, Sec. Agroecology and Ecosystem Services, Volume 8 – 2024, <https://doi.org/10.3389/fsufs.2024.1369571>
 22. Patra, A., Singh, R. P., Kundu, M. S., Kumar, G., Malkani, P., Singh, B.K., Choudhury, S., Kundu, A. and Mukherjee, S. 2023. Green Manuring: A Sustainable Approach for Soil Health Improvement. *Agriculture & Food E-Newsletter*. www.agrifoodmagazine.co.in, Volume 05 -Issue 04; pag. 198-201; E-ISSN2581 – 8317, https://www.researchgate.net/publication/372007803_Green_Manuring_A_Sustainable_Approach_for_Soil_Health_Improvement.
 23. Abdulraheem Mukhtar Iderawumi, Tobe Olalekan Kamal, 2022. Green Manure for Agricultural Sustainability and Improvement of Soil Fertility. *Farming Management* 7 (1) : 1-8 (2022), <https://doi.org/10.31830/2456-8724.2022.FM-101>.
 24. Fernando Munoz, Muñoz, F Villegas, C Moreno and C Posada, 2016. Use of cowpea (*Vigna unguiculata*) as a green manure and its effect on nitrogen (N) requirement and productivity of sugarcane. *Proceedings of the International Society of Sugar Cane Technologists*, volume 29, 2016. ([researchgate.net](https://www.researchgate.net/publication/313847254_Use_of_cowpea_Vigna_unguiculata_as_a_green_manure_and_its_effect_on_nitrogen_N_requirement_and_productivity_of_sugarcane)), https://www.researchgate.net/publication/313847254_Use_of_cowpea_Vigna_unguiculata_as_a_green_manure_and_its_effect_on_nitrogen_N_requirement_and_productivity_of_sugarcane.
 25. Rojas-Velázquez, Montserrat, Rodríguez-Ortiz, J. Carlos, Alcalá-Jáuregui, Jorge A., Díaz-Flores, Paola E., Carballo-Méndez, Fernando J., Zúñiga Valenzuela, Elizabeth, 2020. Greenhouse trial of green manures on soil properties, chard production and environmental implications. *SciELO Revista mexicana de ciencias agrícolas*, Print version ISSN 2007-0934, vol. 11, n. 4, <https://doi.org/10.29312/remexca.v11i4.2104>.
 26. Omolayo J., Olorunwa A., Shi T., Casey B., 2021. Varying drought stress induces morpho-physiological changes in cowpea (*Vigna unguiculata* L.) genotypes inoculated with *Bradyrhizobium japonicum*. *Plant Stress*, Volume 2, December 2021, 100033; <https://doi.org/10.1016/j.stress.2021.100033>.
 27. Buhlebelive Mndzebele, Bhekumthetho Ncube, Melvin Nyathi, Sheku Alfred Kanu, Melake Fessehazion, Tafadzwanashe Mabhaudhi, Stephen Amoo and Albert Theminkosi Modi, 2020. Nitrogen Fixation and Nutritional Yield of Cowpea-Amaranth Intercrop. *Agronomy* 2020, 10(4), 565; <https://doi.org/10.3390/agronomy10040565>.
 28. Sukitprapanon T.S., Jantamenchai M., Tulaphitak D., Vityakon P., 2020. Nutrient composition of diverse organic residues and the irlong-term effects on available nutrients in a tropical sandy soil. *Heliyon*, 2020 Nov; 6 (11): e05601., PMID: 33305035, doi: <https://doi.org/10.1016/j.heliyon.2020.e05601>.
 29. Sukri M.Z, Firgiyanto R., Sugiyarto, Rohman H.F., 2021. The increasing fertility of sandy soils and chili production through the application of organic fertilizers, zeolite and cane blotong. *IOP Conference Series: Earth and Environmental Science*, Volume 672, The 3rd International Conference on Food and Agriculture 7-8 November 2020, Jember, East Java, Indonesia, <https://doi.org/10.1088/1755-1315/672/1/012101>.
 30. Man Singh, A. Singh, S. Singh, R.S. Tripathi, A.K. Singh, D.D. Patra, 2010. Cowpea (*Vigna unguiculata* L. Walp.) as a green manure to improve the productivity of a menthol mint (*Mentha arvensis* L.) intercropping system. *Industrial Crops and Products*, Volume 31, Issue 2, , March 2010, Pages 289-293. <https://doi.org/10.1016/j.indcrop.2009.11.004>.
 31. Ion P., 1988. The use of green manures as a source of organic matter for the fertilization of sands and sandy soils. *Cereals and Technical Plants Magazine*, no. 10, Bucharest.
 32. Davidescu, D., Davidescu, V., 1981. Modern agrochemistry. Editura Acadademia R.S.R., București: 34-205., https://anticariat-ursu.ro/agrochimia-moderna__david-davidescu-velicica-davidescu__147379.html?product_id=147379&srsId=AfmBOoq98xt4OETOIJez_piaDhuAxxJkHt5gKPSmxKkbtIqoy1wLyeg
 33. Popescu C.I., 1964. Experiences regarding increasing the productivity of sands with the help of green manure. *Oltenia sands on the left side of Jiului and their exploitation*, Craiova, <https://www.anticariat-unu.ro/nisipurile-olteniei-din-stanga-jiului-si-valorificarea-lor-vol-vii-supliment-1964-p75030>.
 34. Eliade Gh., Ghinea L., Ștefanic Gh., 1975. Soil microbiology. Ed. Ceres, Bucharest <https://www.targulcartii.ro/gh-stefanic/microbiologia-solului-ceres-1975-5251267>.
 35. Ploae P., Marinică Gh., Gheorghe D., Drăghici I., Drăghici Reta, Șoimu T., 2001. Research concerning economic limits to use water by some agricultural crops on the sandy soils of southern Oltenia. *Scientific*

- Works S.C.C.C.P.N, Dabuleni, vol. XIII, Edsitura Sitech, Craiova, ISBN 973-657-249-8, https://www.scdcpndabuleni.ro/wp-content/uploads/Lucrari-stiintifice-SCDCPN-Dabuleni-Vol_XIII.pdf.
36. Burzo I., 2014. Climate change and its effects on horticultural plants, Ed. Sitech, Craiova, <https://www.scdcpndabuleni.ro/wp-content/uploads/Modificarile-climatice-si-efectele-asupra-plantelor-horticole.pdf>.
 37. Xinyi Yang, Meiqi Lu, Yufei Wang, Yiran Wang, Zhijie Liu and Su Chen, 2021, Response Mechanism of Plants to Drought Stress. *Horticulturae* 2021, 7(3), 50; ISSN: 2311-7524; <https://doi.org/10.3390/horticulturae7030050>.
 38. Mihail DUMITRU, Sorina DUMITRU, Irina CALCIU, Victoria MOCANU, Alexandrina MANEA, Nicoleta VRÎNCEANU, Veronica TÂNASE, Marius EFTENE, Constantin CIOBANU, Ion RÎȘNOVEANU Veronica TÂNASE Mihaela PREDA, 2011. Soil quality monitoring in Romania. Ed. Sitech, Craiova 2011, . <https://www.icpa.ro/proiecte/Proiecte%20nationale/monitoring/atlasICPA.pdf>
 39. <https://www.britannica.com/science/Koppen-climate-classification>.
 40. Alina-Nicoleta PARASCHIV, Aurelia DIACONU, Ștefan NANU, Daniela Valentina POPA, 2023. Research on the dynamics of meteorological phenomena in the south of Oltenia and the establishment of the suitability of the sweet pepper culture for the current climatic conditions, Scientific Papers. Series B, Horticulture, Vol. LXVII, Issue 2, pag. 377-384, PRINT ISSN 2285-5653, CD-ROM ISSN 2285-5661, ONLINE ISSN 2286-1580, ISSN-L 2285-5653, https://horticulturejournal.usamv.ro/pdf/2023/issue_2/Art54.pdf.
 41. Reta Draghici, Iulian Draghici, Aurelia Diaconu, Mihaela Croitoru, Alina Nicoleta Paraschiv, Milica Dima and Mircea Constantinescu, 2019. Utilization of the thermohydric stress in the psamosols area in Southern Oltenia through the cowpea culture | E3S Web of Conferences (e3s-conferences.org). Volume 112, 2019. 8th International Conference on Thermal Equipment, Renewable Energy and Rural Development (TE-RE-RD 2019); Art. No. 03013 ISSN: 2267-1242; <https://doi.org/10.1051/e3sconf/201911203013>
 42. Dincă L., Lucaci D., Iacoban C., Ionescu M., 2012a. Methods of analysis of soil properties and solution. Ed. Tehnică Silvică, <https://editurasilvica.ro/produs/metode-de-analiza-a-proprietatilor-si-solutiei-solului/>
 43. Dincă L., Spârchez G., Dincă M., Blujdea V., 2012b. Organic carbon concentrations and stocks in Romanian mineral forest soils. *Annals of Forest Research* 55 (2): 229-241, <https://afrjournal.org/index.php/afr/article/view/63/91>.
 44. Marinică Gh., Gheorghe D., Ploae P., Baron Milica, Ciolacu Floarea, Ciuciuc Elena, Croitoru Mihaela, Diaconescu A., Drăghici Reta, Drăghici I., Durău Anica, Ifrim Aurelia, Marcu Florentina, Marinică Alisa, Nanu Șt., Ploae Marieta, Rățoi I., Șearpe Doina, Șoimu T., Toma V., Vladu Florentina, 2003. Research on the farming system for sands and sandy soils. SCDCPN Dăbuleni Scientific Works, vol. XV, SITECH Publishing House, Craiova, ISBN 973-657-514-4, pag. 17 – 27, https://www.scdcpndabuleni.ro/wp-content/uploads/Lucrari-stiintifice-SCDCPN-Dabuleni-Vol_XV.pdf.
 45. https://www.gwp.org/globalassets/global/gwp-cee_files/regional/idmp-guide-moldova-ro.pdf.
 46. <https://ro.scribd.com/doc/43754560/Irigarea-Culturilor>
 47. Draghici Reta, 2018. Cowpea, the plant of sandy soils. Sitech publishing house, Craiova, ISBN 978-606-11-6587-2, 183 pages, <https://www.scdcpndabuleni.ro/wp-content/uploads/Fasolita-1.pdf>.
 48. Alves Barros J.R., Francislene A., Oliveira Santos J., Silva R.M., Dantas B.F., Nataniel F.M., 2020. Optimal temperature for germination and seedling development in cowpea seeds. *Revista Colombiana de Ciencias Hortícolas*. Doi: <https://doi.org/10.17584/rcch.2020v14i2.10339>.
 49. Vinu K.S, Ajithkumar B., Arjun Vysak, Harithalekshmi V., Aswathi K.P., 2021. Influence of weather parameters on the growth and yield of cowpea in central zone of Kerala. *Journal of Pharmacognosy and Phytochemistry* 2021; Sp 10(1): 620-622, E-ISSN: 2278-4136 P-ISSN: 2349-8234, . <https://www.phytojournal.com/archives/2021/vol10issue1S/PartJ/S-10-1-116-927.pdf>
 50. Drăghici Reta, Birsoghe Cristina, Paraschiv Alina Nicoleta, Dima Milica, Băjenaru Maria Florentina, Netcu Florentina, 2024. Preliminary results regarding the biological potential of some cowpea genotypes studied in different cropping systems under climate change conditions in southern Oltenia. *Acta Agricola Romanica Field Crops* Tom 6, An 6, Nr. 6.1.1, pag. 63-71, ISSN 2784 – 0948 ISSN – L 2784 – 0948, https://www.asas.ro/Acta%20agricola/ACTA_AGRICOLA_NR.6.1.1.-2024.pdf.
 51. Qirui Cui, Haizheng Xiong, Yufeng Yufeng, Stephen Eaton, Sora Imamura, Jossie Santamaria, Waltram Ravelombola, Richard Esten Mason, Lisa Wood Leandro Angel Mozzoni, and Ainong Shi, 2020. Evaluation of Drought Tolerance in Arkansas Cowpea Lines at Seedling Stage. *HortScience*, Volume 55: Issue 7, 1132–1143, Online ISSN: 2327-9834; <https://doi.org/10.21273/HORTSCI15036-20>.
 52. Anjum, S.A., Xie, X., Wang, L., 2011. Morphological, physiological and biochemical responses of plants to drought stress. *African Journal Agricultural Research* 6: 2026-2032, <https://doi.org/10.5897/AJAR10.027>.
 53. Egashira C., Yamauchi T., Miyamoto Y., Yuasa T., Ishibash I. Y., Iwaya-Inoue M., 2016. Physiological responses of cowpea (*Vigna unguiculata* (L.) Walp) to drought stress during the pod-filling stage. *Japanese Society for Cryobiology and Cryotechnology*. Elsevier. Tokyo. 62(1): 69-75, https://doi.org/10.20585/cryobolcryotechnol.62.1_69_14.

54. Virginia Sánchez-Navarro, Raúl Zornoza, Ángel Faz, Juan A. Fernández, 2019. Does the use of cowpea in rotation with a vegetable crop improve soil quality and crop yield and quality? A field study in SE Spain. *European Journal of Agronomy*, Volume 107, July 2019, Pages 10-17. <https://doi.org/10.1016/j.eja.2019.03.007>.
55. Thidar Hlaing, Kyi Moe, Ei Han Kyaw, Kyaw Ngwe, Myat Moe Hlaing, Htay Htay Oo, 2024. Assessment of Green Manure Crops and their Impacts on Mineralizable Nitrogen and Changes of Nutrient Contents in the Soil. *Asian Soil Research Journal* 8(2):29-38; <https://doi.org/10.9734/asrj/2024/v8i2149>
56. Neelendra Singh Verma, Deepika Yadav, Monika Chouhan, Charu Bhagat and Priya Kochale, 2023. Understanding Potential Impact of Green Manuring on Crop and Soil: A Comprehensive Review. *Biological Forum – An International Journal* 15(10): 832-839(2023), SSN No. (Print): 0975-1130ISSN No. (Online): 2249-3239, https://www.researchgate.net/publication/375768329_Understanding_Potential_Impact_of_Green_Manuring_on_Crop_and_Soil_A_Comprehensive_Review#fullTextFileContent.
57. An Hu, Rui Huang, Guodao Liu, Dongfen Huang and Hengfu Huan, 2022. Effect of Green Manure Combined with Phosphate Fertilizer on Movement of Soil Organic Carbon Fractions in Tropical Sown Pasture. 2022, *Agronomy* 2022, 12(5), 1101; <https://doi.org/10.3390/agronomy12051101>
58. Ioana Andra VLAD, Győző GOJL, Szilard BARTHA, 2023. Supply and distribution degree of some macronutrients in soils polluted with heavy metals nearby the city of Copșa mică. *Scientific Papers. Series A. Agronomy*, Vol. LXVI, No. 2, 2023. ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785 <https://agronomyjournal.usamv.ro/index.php/scientific-papers/current?id=1649>,
59. C. Neagu, G. Oprea., 2006. Effect of nitrogen fertilization on organic matter content of cambic chernozem from Fundulea. *Annals of the Fundulea National Agricultural Research-Development Institute*, 2006, Vol. 73, 151-156 ref. 5. <https://www.cabidigitallibrary.org/doi/full/10.5555/20083100014>
60. Marcelo Laranjeira Pimentel, Iolanda Maria Soares Reis, Maria Lita Padinha Corrêa Romano, Jailson Sousa de Castro, Carlos Ivan Aguilar Vildoso, Eloi Gasparin, Eliandra Freitas de Sia, Leandro Silva de Sousa, 2023. Green manure, a sustainable strategy to improve soil quality: a case study in an oxisol from northern Brazil. *Australian Journal of Crop Science*, 17(6):488-497 (2023) ISSN:1835-2707, doi: <https://doi.org/10.21475/ajcs.23.17.06.p3832>.
61. Zhenfu Wu, Xiaomei Sun, Yueqi Sun, Junying Yan, Yanfeng Zhao, Jie Chen, 2022. Soil acidification and factors controlling topsoil pH shift of cropland in central China from 2008 to 2018. *Geoderma* Volume 408, <https://doi.org/10.1016/j.geoderma.2021.115586>.
62. Mahmoud F. Seleiman, Nasser Al-Suhaibani, Nawab Ali, Mohammad Akmal, Majed Alotaibi, Yahya Refay, Turgay Dindaroglu, Hafiz Haleem Abdul-Wajid, and Martin Leonardo Battaglia, 2021. Drought Stress Impacts on Plants and Different Approaches to Alleviate Its Adverse Effects. *Plants (Basel)*. 2021 Feb; 10(2): 259. <https://doi.org/10.3390/plants10020259>.
63. C. Bora, C.V. Popescu, 2002. The rational use of irrigation in the central area of Oltenia, Alma Publishing House, Craiova, https://catalog.aman.ro/opac/bibliographic_view/353758;jsessionid=E95657651CF8CFBF5BFE4408C8B3ACB6?pn=opac%2FSearch&q=author_sort%3A%22irigatii%22#do_file_type=all&fq=udc%3A63&fq=materiale_type%3A+Carte+tip%C4%83rit%C4%83&level=all&material_type=all&ob=asc&q=author_sort%3A%22irigatii%22&sb=relevance&start=0&view=CONTENT
64. Yared Assefa, Scott Staggenborg, P. V. Vara. Prasad, 2010. Grain Sorghum Water Requirement and Responses to Drought Stress: A Review. *Crop Management*. 9. 10.1094/CM-2010-1109-01-RV. <https://www.researchgate.net/publication/260421900>.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.