

Article

An Evaluation of the Biometric Parameters and Chemical Composition of the Florets, Leaves, and Stalks of Broccoli Plants Grown in Different Soil Types

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Abstract: Soil affects plant growth and development, and it is one of the factors that determine crop yields and quality. Broccoli (*Brassica oleracea* var. *italica* Plenck) plants cv. Cezar were grown in an experiment conducted in 2021–2022 on a horticultural farm. The biometric parameters of broccoli plants were determined in the first stage. The chemical composition of the edible parts of broccoli was determined in the second stage, which involved two experimental factors. The first factor was the edible parts of broccoli: florets, leaves, and stalks. The second factor was the effect of soil type on the chemical composition of the edible parts of broccoli. Albic Luvisol (II) had a significant positive effect on floret height and the number of florets. Leaf yield was significantly lower when broccoli plants were grown in Eutric Cambisol (I) compared with Albic Luvisol (II) and degraded chernozem (III). Soil type had no significant influence on the macronutrient content of broccoli florets, leaves, and stalks, but the accumulation of macronutrients varied across the edible plant parts. The content of iron, zinc and manganese in broccoli plants was not significantly affected by soil type, but soil type exerted a significant effect on copper content.

Keywords: edible parts of broccoli; plants; parameters; yield; minerals; relationships



Citation: Majkowska-Gadomska, J.; Kaliniewicz, Z.; Francke, A.; Sałata, A.; Jadwisieńczyk, K.K. An Evaluation of the Biometric Parameters and Chemical Composition of the Florets, Leaves, and Stalks of Broccoli Plants Grown in Different Soil Types. *Appl. Sci.* **2024**, *14*, 4411. <https://doi.org/10.3390/app14114411>

Academic Editor: Stefano Loppi

Received: 9 April 2024

Revised: 21 May 2024

Accepted: 22 May 2024

Published: 23 May 2024



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1. Introduction

Brassica vegetables are temperate climate crops that can be directly seeded or transplanted out in the field. The selection of vegetable species and cultivars is determined to a large extent by current market needs [1]. Increasing consumer awareness regarding the quality of vegetables and global food security prompts producers to constantly improve the functional properties of foods. An improvement in the quality of the edible parts of vegetables should be accompanied by increased productivity per unit area, whereas the environmental impact of vegetable production should be minimized [2]. This goal can be achieved through the use of organic and profitable raw materials [3].

Broccoli (*Brassica oleracea* var. *italica* Plenck) is not very popular in Poland, although it is relatively easy to cultivate. This vegetable species can be frozen because freezing does not change its dark green color or taste [4–6]. Broccoli is appreciated by consumers due to its high nutritional value, including a high content of provitamin A (β -carotene), vitamin B1, minerals, and dietary fiber [4,7], as well as potential anticarcinogenic properties [8–10]. Broccoli plants are a rich source of vitamin C whose concentration ranges from 54 to 119.8 mg per 100 g of raw broccoli. Raw broccoli is considered most nutritious [11,12]. Not

only flower heads and florets, but also leaves and stalks can be eaten. Broccoli is available in grocery stores all year round, both fresh and frozen [5].

Substrate (soil) affects plant growth and development, and it is one of the factors that determine crop yield and quality. According to estimates, 60% of the world's arable soils contribute to limiting plant growth, and both mineral deficiencies and excess may exert negative effects [13,14]. Soil fertility is the key to adequate plant nutrition, since nutrients have to be supplied at the right time and in the right quantities [15,16]. Nutrient supply and plant growth are often inhibited by unfavorable soil conditions, including pH and salinity, which influence the phytoavailability of minerals and the concentrations of toxic elements in the soil solution [17]. However, the soil's ability to supply essential nutrients to plants is affected not only by its properties. Soil must also support root growth, so that growing plants can take up sufficient amounts of available nutrients [18]. One of the contemporary challenges is to produce high-quality foods. Therefore, efforts are being made to maximize the use of crops and optimize their growing conditions.

In view of the above, the present study was undertaken to determine the effect of soil type on the yield and nutritional value of broccoli florets, leaves and stalks. The research hypothesis postulates that soil type affects the biometric parameters and chemical composition of the edible parts of broccoli, and induces changes in the morphological and chemical parameters of broccoli plants. The aim of this study was to evaluate the influence of different soil types on the biometric parameters of broccoli plants and the mineral content of florets, leaves and stalks.

2. Materials and Methods

2.1. Study Site and Experimental Factors

Broccoli plants cv. Cezar were grown in an experiment conducted in 2021–2022 on a horticultural farm (52°37'17.6" N, 18°30'07.9" E and 53°12'61.1" N, 19°01'91.7" E) in the Kuyavian–Pomeranian Voivodeship (mid-northern Poland). Due to minor differences in the analyzed parameters, the results were expressed as the mean values from both cultivation dates. The experiment consisted of two stages. The biometric parameters of broccoli plants were determined in the first stage. The chemical composition of the edible parts of broccoli was determined in the second stage, which involved two experimental factors. The first factor was the edible parts of broccoli: florets, leaves, and stalks. The second factor was the effect of soil type on the growth and yield of broccoli plants, and the chemical composition of the edible parts of broccoli. The following soil types were analyzed [19]:

- I. Eutric Cambisol, a subtype of Cambisols (quality class IVa and good rye complex according to the Polish soil classification system), developed from boulder clay, humus horizon—30 cm;
- II. Albic Luvisol (Arenic), a subtype of Luvisols, deeply flattened, developed from clay (quality class IIIa according to the Polish soil classification system);
- III. Degraded chernozem, developed from light loam with low sand content, underlain by medium-heavy loam, humus content—1.9 (quality class IVb according to the Polish soil classification system).

The chemical composition of the analyzed soil types is presented in Table 1.

Table 1. Composition of experimental soils.

Soil	pH-H ₂ O	N-NO ₃	P	K (mg dm ⁻³)	Mg	N-NH ₄
I	7.1	18	175	152	84	29
II	8.3	48	219	364	132	30
III	8.3	29	230	306	142	30

2.2. Experimental Design

Broccoli seedlings were grown in a greenhouse. Seeds were sown in the first ten days of March 2021 and 2022, in plug trays with 54 cells each, and a cell volume of 0.11 dm³. The plug trays were filled with the suitable substrate for growing broccoli.

The seedlings were grown in accordance with the methodology of integrated broccoli protection developed by the National Institute of Horticultural Research and Łobanowski [2]. No disease or pest symptoms were observed during seedling production, so no pesticides were used. Seedlings were hardened off in BBCH stage 15, and transplanted to the field.

Broccoli was grown in experimental plots previously used for growing beans for dry seeds. The plots were prepared in line with the Integrated Broccoli Production Methods [2]. The substrates were analyzed for chemical composition (Table 1) before broccoli cultivation, with the use of universal methods. The concentrations of nitrogen (N-NO₃), phosphorus (P), potassium (K), and magnesium (Mg), and the levels of salinity and pH were measured. The content of N-NO₃ and P in the analyzed soils was determined by colorimetry (UV-1201V spectrophotometer, Shimadzu Corporation Kyoto, Kyoto, Japan) with the use of phenoldisulfonic acid and the vanadate-molybdate reagent, respectively; K content was determined by atomic emission spectrometry (AES) (BWB Technologies UK Ltd. Flame Photometers, Newbury, UK); Mg content was determined by atomic absorption spectrophotometry (AAS) (AAS1N, Carl Zeiss Jena, Jena, Germany), following extraction with 0.01 M CaCl₂. Salinity and pH were measured using the conductometric method (N5773 conductivity meter, Tel-Eko Wrocław, Wrocław, Poland) and the potentiometric method, respectively.

Before planting, soil was prepared with the use of a cultivation unit (tiller + drag harrow). Seedlings were planted in mid-May using a carousel-type vegetable planter. Plant spacing was 62.5–67.5 × 40–50 cm. Ten plants constituted one replicate. The experiment was performed in triplicate.

The fertilization regime for broccoli was determined based on the nutrient requirements of plants, expected yields, soil type, soil nutrient composition, and crop rotation. The mineral content of soil before broccoli production is presented in Table 1. Supplemental nitrogen was applied as ammonium nitrate at 150–200 kg ha⁻¹ (50–75% of the total nitrogen rate) under the cultivation unit. The remaining portion of nitrogen was applied in two equal splits, in weeks 3 and 5 of cultivation. Borax was applied at 10 kg ha⁻¹ to ensure adequate micronutrient levels in soil. Seedlings were irrigated at 10–15 mm immediately after planting. Moisture content was maintained at 20–25 mm after rooting, and at 30 mm during flower head development. During cultivation, broccoli plants received 100–150 mm of water (i.e., 1000–1500 m³ ha⁻¹) via a sprinkler system. A deep well located on the farm was used as the source of water.

Plant protection products were applied to protect broccoli plants and suppress the action of harmful organisms that were regularly monitored. The decision of whether and when to apply plant protection measures was made based on the results of monitoring and the relevant harmful organism threshold levels. Broccoli heads were harvested at maturity, in the first ten days of August.

2.3. Biometric Parameters of Broccoli Plants

During the growing season, overall plant health was evaluated by measuring leaf greenness (SPAD index). The measurements were performed twice, in the second true leaf unfolded stage and on the last day of the experiment, with the use of the SPAD-502 chlorophyll meter (Konica Minolta Inc., Wrocław, Poland), on all leaves of a given plant. The measurements were repeated for five plants, and the obtained values were averaged. At the completion of the experiment, the height of each plant was measured, and the inflorescences were cut out. Flower head height was measured from the base of a branching arm to the tip, within an accuracy of ±1 mm, with the use of a ruler. The number of leaves was determined on each plant, and leaves were cut out and weighed on the Radwag PST 750 R2 laboratory scale (Radwag, Radom, Poland) to the nearest gram. The inflorescences

cut out from each plant were weighed using the same laboratory scale. Stalks and florets were separated by hand from the inflorescences, and their weights were determined with the Radwag PST 750 R2 scale. The height and width of each floret were determined. The total yields of broccoli plants, calculated as the combined yields of florets, leaves, and stalks, and marketable yield were expressed in t ha^{-1} .

2.4. Mineral Composition of Broccoli Florets, Leaves and Stalks

In each treatment, florets, leaves, and stalks were collected and analyzed in their respective groups to determine the mineral composition of edible plant parts. Chemical analyses were performed in triplicate, in dry plant materials collected during the first harvest. The concentrations of the following macronutrients: total nitrogen (N-total), phosphorus (P), potassium (K), calcium (Ca), and magnesium (Mg), and micronutrients: copper (Cu), zinc (Zn), boron (B), and manganese (Mn) were analyzed in dry and wet mineralized plant materials. Plants were dried in a Binder ED400 dryer (Binder GmbH, Tuttlingen, Germany), at a temperature of 65 °C for 24 h, and next, they were ground in a Grindomix GM300 knife mill (Retsch GmbH, Haan, Germany). Before the analysis of macronutrient content, samples of different plant parts were wet-mineralized in H_2SO_4 with the addition of H_2O_2 as the oxidizing agent, with the use of the SpeedDigestor K-439 unit (Büchi Labortechnik AG, Flawil, Switzerland). Before the analysis of micronutrient content, samples of different plant parts were wet mineralized in a mixture of $\text{HNO}_3 + \text{HClO}_4 + \text{HCl}$ with the use of the CEM Mars 5 Digestion Oven (CEM Corporation, Matthews, NC, USA).

In all groups of the edible parts of broccoli plants grown in the tested substrates, the content of macronutrients and micronutrients was determined by the following methods:

- N-total—Kjeldahl method;
- P—colorimetric method (UV-1201V spectrophotometer, Shimadzu Corporation Kyoto, Tokyo, Japan);
- K and Ca—atomic emission spectrometry (AES) (Flame Photometers, BWB Technologies Ltd., Newbury, UK);
- Mg—atomic absorption spectrometry (AAS) (AAS1N, Carl Zeiss Jena, Jena, Germany);
- Cu, Zn, B, and Mn—AAS (AA-6800, Shimadzu Corporation, Kyoto, Japan).

2.5. Statistical Analysis

The results were analyzed statistically using the Statistica Pl ver. 13.3 software package (TIBCO, Paolo Alto, CA, USA). The statistical procedures included descriptive statistics and analysis of variance (ANOVA). Calculations were performed at a significance level of $\alpha = 0.05$. The mean values of the examined parameters of broccoli plants and inflorescence parts, and the concentrations of macronutrients and micronutrients, were calculated using descriptive statistics. The significance of differences between the means was estimated by ANOVA, and homogeneous groups were identified by Tukey's test.

3. Results and Discussion

3.1. Biometric Parameters of Broccoli Plants

Differences in the biometric parameters of broccoli plants grown in the analyzed soils are presented in Figure 1. Significant differences were noted only in flower head height and the number of florets between broccoli plants grown in soil II vs. soils I and III. In comparison with plants grown in soils I and III, plants grown in soil II were characterized by the highest average SPAD index; plant height; flower head height; percentage of flower head in total plant weight; number of florets, floret height, and floret width; and the lowest number of leaves and the lowest percentage of leaves in total plant weight.

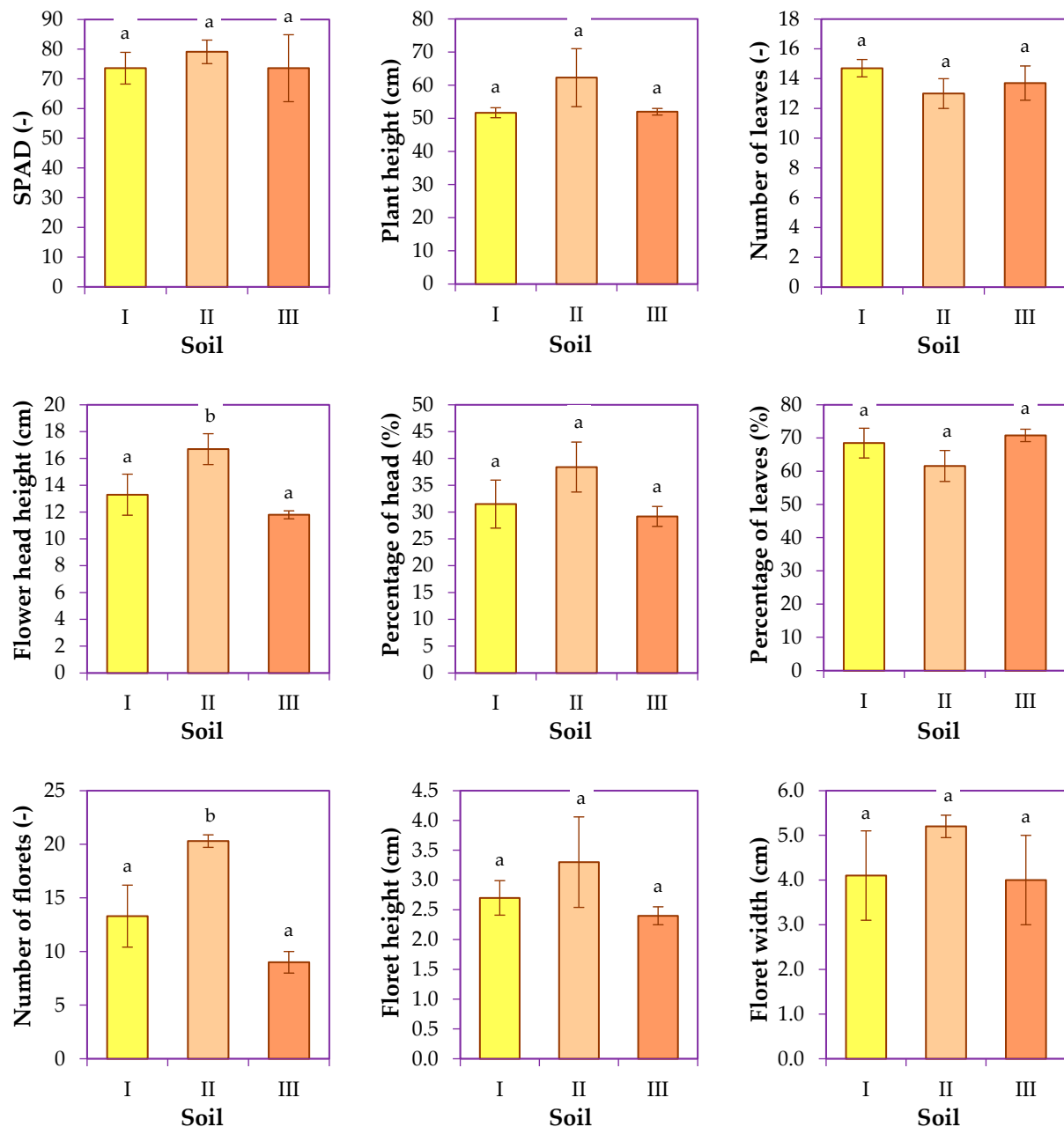


Figure 1. Effect of soil type on the biometric parameters of broccoli plants: a, b—various letters denote significant differences at $p < 0.05$ (Tukey's test); I—Eutric Cambisol; II—Albic Luvisol (Arenic); III—degraded chernozem.

These results indicate that soil II is most suitable for growing broccoli. Luvisols, classified as brown earth soils, cover approximately 30% of land area in Poland. The presence of sedimentary, intrusive, and porous rocks promotes leaching. Therefore, luvisols are formed under good drainage conditions from various formations, most often from loess, water dust, glacial till and sands overlying clay or heavier sandy formations. Luvisols have a well-developed profile with well-defined genetic horizons. In terms of grain size, Luvisols contain particles of silt formations, light clay, and sand underlain by clay, with no skeleton or a weak skeleton. The pH of Luvisols varies; in the present experiment, it was near-neutral, which was conducive to broccoli cultivation [20]. In soils I and III, the values of all analyzed parameters were satisfactory, but less desirable than in soil II, which implies that these types of soil were less suitable for growing broccoli. In comparison with plants grown in soil II, plants grown in soils I and III were smaller, they produced

smaller inflorescences, smaller florets, and a higher number of leaves characterized by higher weight.

The SPAD index of broccoli plants grown in the analyzed soils ranged from 62.5% (soil III) to 83.3% (soil II); its average value was 73.6% in plants grown in soils I and III, and 79.1% in those grown in soil II. According to Michelon et al. [21], the chlorophyll content of leaves (a physiological parameter) declines with decreasing nutrient concentrations in soil. In the current study, nutrient levels were similar in all examined soil types, but soil II was most abundant in nutrients.

Plant height was lowest in soil I (50 cm) and highest in soil II (72 cm). The average plant height ranged from 51.7 cm (soil I) to 62.3 cm (soil II). Flower head height ranged from 11.5 cm (soil III) to 18.0 cm (soil II), and the average value of this parameter varied from 11.8 cm (soil III) to 16.7 cm (soil III). The flower head of broccoli plants is surrounded by leaves whose number changed within a relatively narrow range of 12 (soil II) to 15 (soils I and III). Leaves have a higher share of total plant weight than the flower head. The average ratio of these plant parts was 62:38 (soil II) to 71:29 (soil III). The flower head consists of florets whose number ranged from 8 (soil III) to 21 (soil II). Broccoli plants grown in soils I, II and III produced 13, 20 and 9 florets on average, respectively. The average flower size was largest in plants grown in soil II (height—3.3 cm, width—5.2 cm), and smallest in plants grown in soil III (height—2.4 cm, width—4.0 cm). Similar values of biometric parameters of broccoli plants were reported by Tarafder et al. [22].

3.2. Broccoli Yields

Differences in the yield of broccoli plants grown in the analyzed soils are presented in Figure 2. Broccoli plants grown in soil II were characterized by the most favorable biometric parameters, which was also reflected in the highest yields. The average flower head yield ranged from 18.6 t ha⁻¹ (soil III) to 28.8 t ha⁻¹ (soil II), and the differences in yield between soil II and soils I and III were significant. The yield of leaves from plants grown in soil I was significantly lower than the yields achieved when plants were grown in soils II and III. The average leaf yield ranged from 40.8 t ha⁻¹ (soil I) to 45.8 t ha⁻¹ (soil II). The total yield of broccoli plants ranged from 57.7 t ha⁻¹ (soil I) to 80.0 t ha⁻¹ (soil II), and the average value of this parameter reached 59.7 t ha⁻¹ in soil I, 74.6 t ha⁻¹ in soil II, and 63.6 t ha⁻¹ in soil III. The differences in total yield between soil II vs. soils I and III were significant. Broccoli plants grown in soil II were also characterized by the highest marketable yield of flower heads (12.2 t ha⁻¹ on average), and the difference in this parameter relative to plants grown in soil III was significant. Similar yields of two broccoli hybrids were noted by Hamza and AL-Taey [23]. In the cited study, organic fertilizers exerted a particularly positive effect, which indicates that a higher content of organic compounds in soil promotes higher yields.

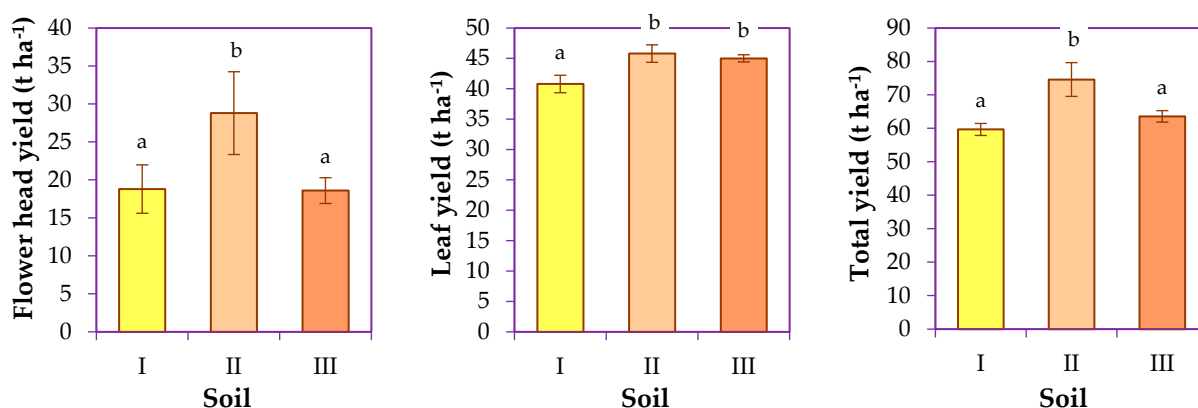


Figure 2. Cont.

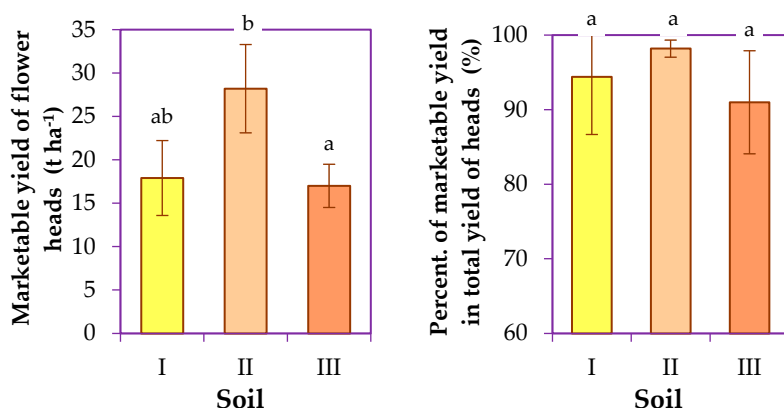


Figure 2. Effect of soil type on broccoli yields: a, b—various letters denote significant differences at $p < 0.05$ (Tukey's test); I—Eutric Cambisol; II—Albic Luvisol (Arenic); III—degraded chernozem.

No significant differences were found in the percentage of marketable yield in the total yield of flower heads, but this parameter was highest in broccoli plants grown in soil II (98.2%) and lowest (although still satisfactory) in plants grown in soil III (91.0%).

3.3. Chemical Composition of Broccoli Plants

Vegetables of the family Brassicaceae are a rich source of vitamins and minerals. They are characterized by high nutritional value, medicinal and health-promoting properties, and high antioxidant activity. The consumption of cruciferous vegetables has also been linked to a reduced risk of developing cancer [6].

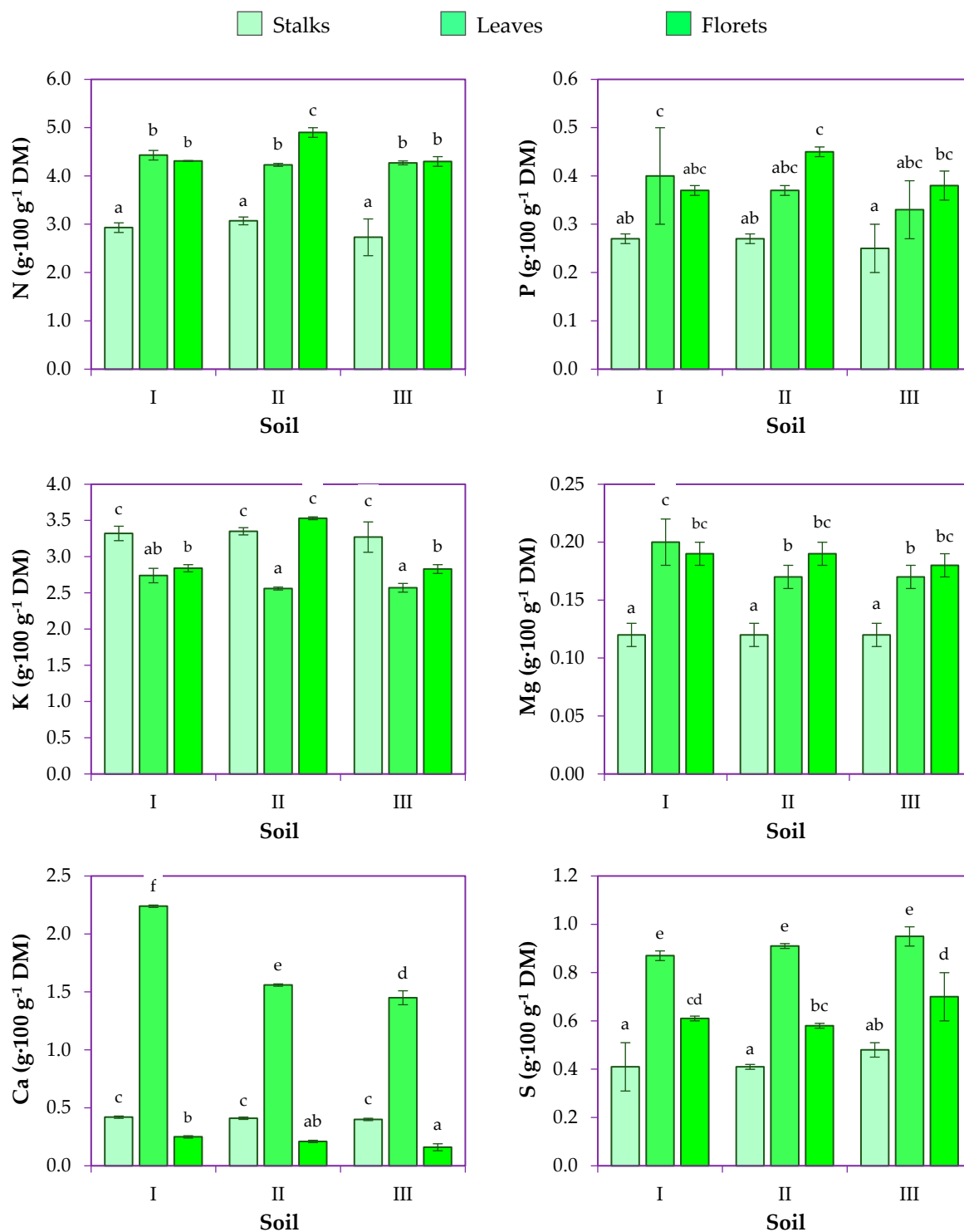
3.3.1. Macronutrient Content

The effect of soil type on the macronutrient (mineral) content of the edible parts of broccoli plants is presented in Table 2 and Figure 3. It was found that macronutrient concentrations were not significantly affected by soil type, but the accumulation of macronutrients varied across the edible plant parts (florets, leaves, and stalks). The uptake of potassium and calcium by plant parts may vary depending on soil type. Plant nutrient availability is determined by nutrient concentrations in the soil solution, and nutrient ratios [24].

According to Taiz and Zaiger [25], nitrogen is one of the major nutrients in crop production. It affects seedling emergence and leaf area expansion. In the present experiment, nitrogen accumulation was significantly lower in stalks than in leaves (by approx. 32% on average) and florets (by approx. 35% on average). Nitrogen accumulation was highest in the florets of broccoli plants grown in soil II ($4.9 \text{ g } 100 \text{ g}^{-1} \text{ DM}$ on average), and lowest in the florets of broccoli plants grown in soil III. An analysis of the content of magnesium and phosphorus in the edible parts of broccoli plants revealed similar relationships. On average, florets contained from 18 to $19 \text{ g } 100 \text{ g}^{-1} \text{ DM}$ of magnesium, and from 0.37 to $0.45 \text{ g } 100 \text{ g}^{-1} \text{ DM}$ of phosphorus; the respective values were around 11% and 15% lower in leaves (excluding broccoli plants grown in soil I— $20 \text{ g } 100 \text{ g}^{-1} \text{ DM}$ and $0.40 \text{ g } 100 \text{ g}^{-1} \text{ DM}$), and around 36% and 37% lower in stalks. Potassium accumulation was generally highest in stalks (from 3.27 to $3.35 \text{ g } 100 \text{ g}^{-1} \text{ DM}$ on average), although the florets of broccoli plants grown in soil II had the highest potassium content ($3.53 \text{ g } 100 \text{ g}^{-1} \text{ DM}$). Potassium content was lowest in leaves, around 21% lower on average than in stalks. In turn, the accumulation of calcium and sulfur was highest in leaves (from 1.45 to $2.24 \text{ g } 100 \text{ g}^{-1} \text{ DM}$ and from 0.87 to $0.95 \text{ g } 100 \text{ g}^{-1} \text{ DM}$, respectively). In comparison with leaves, calcium content was around 76% lower in stalks and around 88% lower in florets, whereas sulfur content was around 52% lower in stalks and around 31% lower in florets. Similar results were reported by Liu et al. [26]. Calcium is phloem immobile, similarly to manganese, and the delivery of these nutrients to developing florets is limited in relation to other mineral elements, such as zinc and phosphorus [27,28].

Table 2. *p*-value in ANOVA of the macronutrient content of broccoli florets, leaves, and stalks.

Factor	N	P	K	Mg	Ca	S
Soil (A)	0.666	0.536	0.463	0.694	0.663	0.665
Edible plant part (B)	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Interaction (A × B)	0.008	0.250	<0.001	0.053	<0.001	0.439

**Figure 3.** Effect of soil type on the macronutrient content of broccoli stalks, leaves and florets: a, b, c, d, e, f—various letters denote significant differences at *p* < 0.05 (Tukey's test); I—Eutric Cambisol; II—Albic Luvisol (Arenic); III—degraded chernozem.

3.3.2. Micronutrient Content

The effect of soil type on the micronutrient (mineral) content of the edible parts of broccoli plants (florets, leaves, and stalks) is presented in Table 3 and Figure 4. It was found that soil type had no significant influence on the concentrations of iron, zinc, and manganese, whereas it significantly affected copper content. Micronutrient accumulation patterns varied across the analyzed plant parts, and broccoli plants grown in different soils differed in the uptake of zinc and manganese (interaction between soil type and the micronutrient content of edible plant parts).

Table 3. *p*-value in ANOVA of the micronutrient content of broccoli florets, leaves, and stalks.

Factor	Cu	Fe	Zn	Mn
Soil (A)	0.001	0.902	0.437	0.968
Edible plant part (B)	0.001	<0.001	<0.001	<0.001
Interaction (A × B)	0.359	0.053	<0.001	<0.001

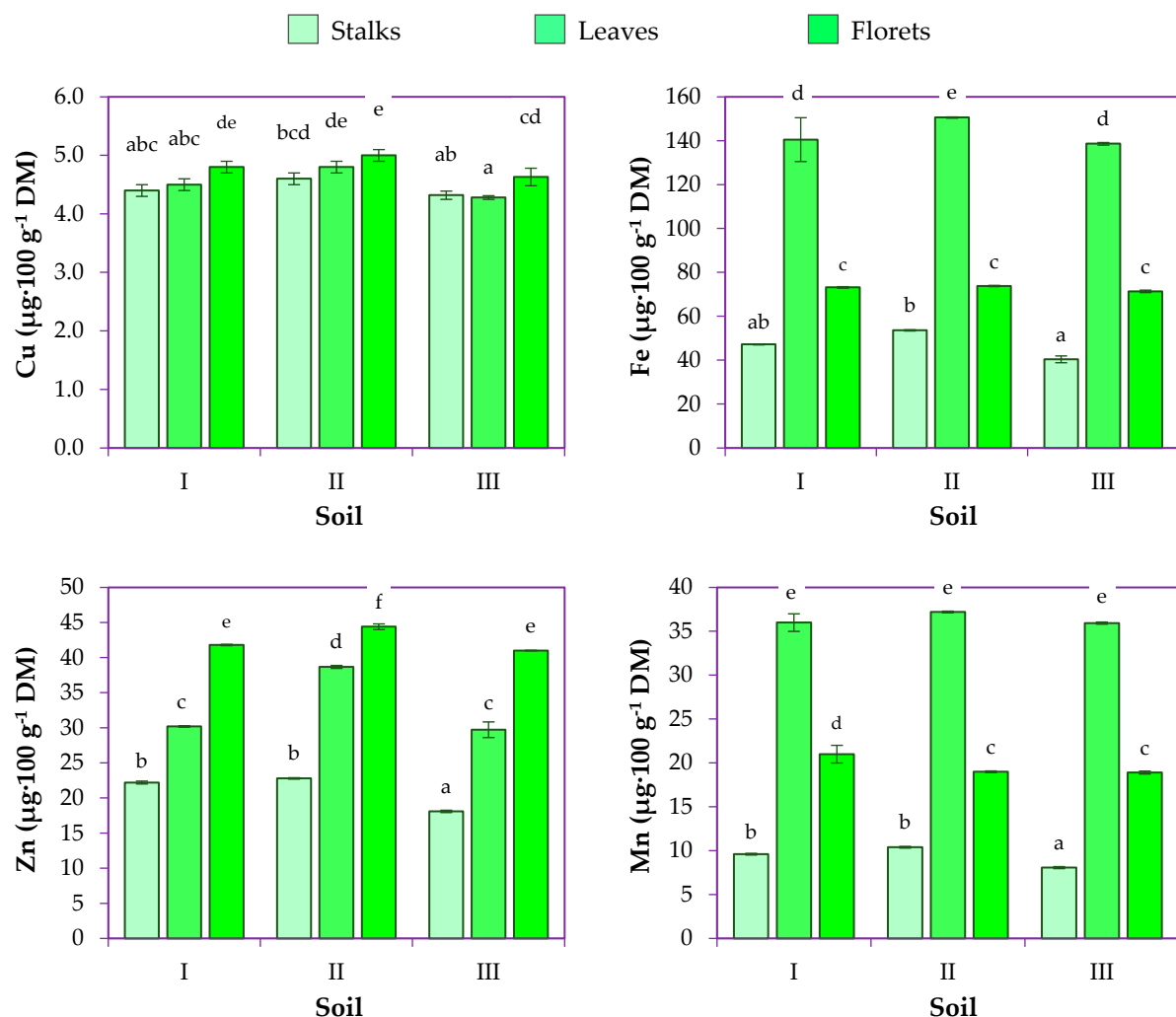


Figure 4. Effect of soil type on the micronutrient content of broccoli stalks, leaves and florets: a, b, c, d, e, f—various letters denote significant differences at $p < 0.05$ (Tukey's test); I—Eutric Cambisol; II—Albic Luvisol (Arenic); III—degraded chernozem.

The content of copper and zinc was highest in the florets ($5.0\text{ }\mu\text{g}\text{ }100\text{ g}^{-1}\text{ DM}$ and $44.4\text{ }\mu\text{g}\text{ }100\text{ g}^{-1}\text{ DM}$, respectively), and the content of iron and manganese was highest in the leaves ($150.6\text{ }\mu\text{g}\text{ }100\text{ g}^{-1}\text{ DM}$ and $37.2\text{ }\mu\text{g}\text{ }100\text{ g}^{-1}\text{ DM}$, respectively) of broccoli plants grown in soil II. In comparison with the micronutrient content of florets, leaves contained

less copper (by approx. 6% on average), more iron (by approx. 97% on average), less zinc (by approx. 23% on average), and more manganese (by approx. 86% on average). In comparison with the micronutrient content of leaves, stalks contained less copper (by approx. 8% on average), iron (by approx. 35% on average), zinc (by approx. 51% on average), and manganese (by approx. 52% on average). The greatest disproportions in micronutrient concentrations were noted with regard to the manganese content of leaves and stalks, and the smallest—with regard to the copper content of stalks and leaves. These results corroborate the findings of Marschner [27] and Page and Feller [28].

4. Conclusions

Albic Luvisol (II) had a significant positive effect on floret height and the number of florets. Leaf yield was significantly lower when broccoli plants were grown in Eutric Cambisol (I) compared with Albic Luvisol (II) and degraded chernozem (III).

Soil type had no significant influence on the macronutrient content of broccoli florets, leaves, and stalks, but the accumulation of macronutrients varied across the edible plant parts.

The content of iron, zinc and manganese in broccoli plants was not significantly affected by soil type, but soil type exerted a significant effect on copper content.

Soil II, i.e., Albic Luvisol (Arenic), a subtype of Luvisols that is deeply flattened, developed from clay (quality class IIIa according to the Polish soil classification system), is most suitable and recommended for broccoli cultivation and production.

Author Contributions: Conceptualization, J.M.-G.; methodology, J.M.-G., A.F. and K.K.J.; software, Z.K.; validation, Z.K.; formal analysis, Z.K. and A.S.; investigation, Z.K.; resources, J.M.-G. and A.F.; data curation, J.M.-G., A.F. and K.K.J.; writing—original draft preparation, J.M.-G. and Z.K.; writing—review and editing, J.M.-G., Z.K. and A.S.; visualization, J.M.-G. and A.F.; supervision, J.M.-G., Z.K. and A.S.; project administration, J.M.-G. and Z.K.; funding acquisition, J.M.-G. and A.F. All authors have read and agreed to the published version of the manuscript.

Funding: The results presented in this paper were obtained as part of a comprehensive study financed by the University of Warmia and Mazury in Olsztyn, Faculty of Agriculture and Forestry, Department of Agroecosystems and Horticulture, 30.610.016-110. Funded by the Minister of Science under the “Regional Initiative of Excellence Program”.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflicts of interest.

References

- Restrepo, A.P.; Medina, E.; Pérez-Espinosa, A.; Agulló, E.; Bustamante, M.A.; Mininni, C.; Bernal, M.P.; Moral, R. Substitution of peat in horticultural seedlings: Suitability of digestate-derived compost from cattle manure and maize silage codigestion. *Commun. Soil Sci. Plant Anal.* **2013**, *44*, 668–677. [[CrossRef](#)]
- Łobanowski, G. *Integrated Broccoli Production Methods, revised*, 2nd ed.; Plant Health and Seed Inspection Service PIORIN: Warsaw, Poland, 2020. (In Polish)
- Gajewski, M. *Przechowalnictwo Warzyw [Vegetable Storage]*; SGGW: Warsaw, Poland, 2005. (In Polish)
- Gębczyński, P. Quantitative changes of selected chemical components during freezing and storage of primary and secondary broccoli inflorescences. *Acta Sci. Pol. Technol. Aliment.* **2003**, *2*, 31–39.
- Szydłowska, A.; Czarniecka-Skubina, E. Effect of cooking methods and storage after cooking on temperature, yield and sensory quality of broccoli. *Zywn. Nauk. Technol. Ja.* **2006**, *1*, 117–132.
- Bell, L.; Oruna-Concha, M.J.; De Haro-Bailon, A. Editorial: Nutritional quality and nutraceutical properties of Brassicaceae (Cruciferae). *Front. Nutr.* **2023**, *10*, 1292964. [[CrossRef](#)] [[PubMed](#)]
- Zalewska-Korona, M. The content of chosen biologically active compounds in different cultivars of broccoli (*Brassica oleracea* var. *Italica*). *Ann. UMCS Sec. E Agric.* **2004**, *59*, 2033–2038.

8. Vermeulen, M.; Klöpping-Ketelaars, I.W.; van den Berg, R.; Vaes, W.H.J. Bioavailability and kinetics of sulforaphane in humans after consumption of cooked versus raw broccoli. *J. Agric. Food Chem.* **2008**, *56*, 10505–10509. [\[CrossRef\]](#)
9. Yagishita, Y.; Fahey, J.W.; Dinkova-Kostova, A.T.; Kensler, T.W. Broccoli or sulforaphane: Is it the source or dose that matters? *Molecules* **2019**, *24*, 3593. [\[CrossRef\]](#)
10. Ilahy, R.; Tlili, I.; Pék, Z.; Montefusco, A.; Siddiqui, M.W.; Homa, F.; Hdider, C.; R'Him, T.; Lajos, H.; Lenucci, M.S. Pre- and post-harvest factors affecting glucosinolate content in broccoli. *Front. Nutr.* **2020**, *7*, 147. [\[CrossRef\]](#)
11. Sharifova, S.; Hasanov, S.; Babayev, A.; Guliyev, N. Some characteristics of the newly obtained constant sweet pepper (*Capsicum annum* L.) hybrids. *Ratar. Povrt.* **2012**, *49*, 122–125. [\[CrossRef\]](#)
12. Yıldırım, E.; Cil, B.; Ekinci, M.; Turan, M.; Dursun, A.; Gunes, A.; Kul, R.; Kıtır, N. Effects of intercropping system and nitrogen fertilization on land equivalent ratio, yield and mineral content of broccoli. *Acta Sci. Pol. Hortorum Cultus* **2020**, *19*, 101–109. [\[CrossRef\]](#)
13. Cakmak, I. Plant nutrition research: Priorities to meet human needs for food in sustainable ways. *Plant Soil* **2002**, *247*, 3–24. [\[CrossRef\]](#) [\[PubMed\]](#)
14. Schjoerring, J.K.; Cakmak, I.; White, P.J. Plant nutrition and soil fertility: Synergies for acquiring global green growth and sustainable development. *Plant Soil* **2019**, *434*, 1–6. [\[CrossRef\]](#)
15. Johnston, A.M.; Bruulsema, T.W. 4R nutrient stewardship for improved nutrient use efficiency. *Procedia Eng.* **2014**, *83*, 365–370. [\[CrossRef\]](#)
16. Withers, P.J.A.; Doody, D.G.; Sylvester-Bradley, R. Achieving sustainable phosphorus use in food systems through circularisation. *Sustainability* **2018**, *10*, 1804. [\[CrossRef\]](#)
17. White, P.J.; Greenwood, D.J. Properties and management of cationic elements for crop growth. In *Soil Conditions and Plant Growth*; Gregory, P.J., Nortcliff, S., Eds.; Blackwell Publishing: Oxford, UK, 2013; pp. 160–194. [\[CrossRef\]](#)
18. White, P.J.; George, T.S.; Dupuy, L.X.; Karley, A.J.; Valentine, T.A.; Wiesel, L.; Wishart, J. Root traits for infertile soils. *Front. Plant Sci.* **2013**, *4*, 193. [\[CrossRef\]](#) [\[PubMed\]](#)
19. *World Reference Base for Soil Resources 2014—International soil Classification System for Naming Soils and Creating Legends for Soil Maps, Update 2015*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2015.
20. Kabała, C. Luvisols and related clay-illuvial soils (gleby płowe)—soils of the year 2023. Current view of their origin, classification and services in Poland. *Soil Sci. Ann.* **2023**, *74*, 177034. [\[CrossRef\]](#)
21. Michelon, N.; Pennisi, G.; Myint, N.O.; Orsini, F.; Gianquinto, G. Optimization of substrate and nutrient solution strength for lettuce and Chinese cabbage seedling production in the semi-arid environment of central Myanmar. *Horticulturae* **2021**, *7*, 64. [\[CrossRef\]](#)
22. Tarafder, S.K.; Biswas, M.; Sarker, U.; Ercisli, S.; Okcu, Z.; Marc, R.A.; Golokhvast, K.S. Influence of foliar spray and post-harvest treatments on head yield, shelf-life, and physicochemical qualities of broccoli. *Front. Nutr.* **2023**, *10*, 1057084. [\[CrossRef\]](#) [\[PubMed\]](#)
23. Hamza, O.M.; AL-Taey, D.K.A. A study on the effect of glutamic acid and benzyl adenine application upon growth and yield parameters and active components of two broccoli hybrids. *Int. J. Agric. Stat. Sci.* **2020**, *16* (Suppl. 1), 1163–1167.
24. Kasperczyk, M.; Szewczyk, W.; Kacorzyk, P. Effect of farmyard manure and mineral fertilizers on nutrients uptake from meadow and chemical properties of soil. *Fragm. Agron.* **2010**, *27*, 39–44.
25. Taiz, L.; Zeiger, E. *Plant Physiology*, 4th ed.; Artmed: Porto Alegre, Brazil, 2009.
26. Liu, M.; Zhang, L.; Ser, S.L.; Cumming, J.R.; Ku, K.-M. Comparative phytonutrient analysis of broccoli by-products: The potentials for broccoli by-product utilization. *Molecules* **2018**, *23*, 900. [\[CrossRef\]](#) [\[PubMed\]](#)
27. Marschner, H. *Mineral Nutrition of Higher Plants*, 2nd ed.; Academic Press: San Diego, CA, USA, 1995.
28. Page, V.; Feller, U. Heavy metals in crop plants: Transport and redistribution processes on the whole plant level. *Agronomy* **2015**, *5*, 447–463. [\[CrossRef\]](#)

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