agronomy

MDPI

Article

Evaluation of the Role of Legumes in Crop Rotation Schemes of Organic or Conventionally Cultivated Cabbage

Dionisios Yfantopoulos [1], Georgia Ntatsi [1,*], Anestis Karkanis [2] and Dimitrios Savvas [1]

1 Laboratory of Vegetable Production, Department of Crop Science, Agricultural University of Athens, 11855 Athens, Greece; yfantopoulos@aua.gr (D.Y.); dsavvas@aua.gr (D.S.)
2 Laboratory of Weed Science, Department of Agriculture Crop Production and Rural Environment, University of Thessaly, 38446 Volos, Greece; akarkanis@uth.gr
* Correspondence: ntatsi@aua.gr; Tel.: +30-210-5294532

Abstract: Cabbage is an annual vegetable crop species cultivated throughout the year. The development of high-yielding cabbage hybrids and the optimization of several agronomic management practices such as fertilization and crop rotation have resulted in increased soil fertility, crop yield and product quality. This study aimed to investigate the effects of the farming system (organic and conventional) and the applied rotation scheme on soil nutrient content, head yield and the nutrient content of cabbage. The preceding crops included either pea (P), faba bean (F) or cabbage (C), and thus, the rotation schemes were P-C, F-C and C-C. Sheep manure was applied in the organic farming system, and the inorganic fertilizer 11-15-15 (N-P_2O_5-K_2O) was applied to the conventionally cultivated plants. The results reveal an interaction between the farming system and the preceding crop for the head yield, with the lowest values (57.00 t ha^{-1} and 53.87 t ha^{-1} in 2015/2016 and 2016/2017, respectively) recorded in plots where cabbage was cultivated as a preceding crop under the organic farming system. The N, P and K contents in head tissues were affected only by the farming system, with the greatest values recorded in the conventional farming system. Both factors affected the nutrient content in the soil. Specifically, the highest values of NO_3^- and total N content in the soil were recorded in the P-C and F-C rotations, and the K content was higher in the continuous cabbage cropping system (C-C). Moreover, the NO_3^-, P and K contents in the soils were higher in the conventional farming system compared to the organic system. To conclude, combining inorganic fertilization in a crop rotation scheme with legume species such as pea and faba bean as preceding crops for cabbage can result in increased soil fertility and head yield.

Keywords: cabbage; faba bean; nutrient content; organic farming; pea; preceding crops; soil fertility

Citation: Yfantopoulos, D.; Ntatsi, G.; Karkanis, A.; Savvas, D. Evaluation of the Role of Legumes in Crop Rotation Schemes of Organic or Conventionally Cultivated Cabbage. *Agronomy* **2024**, *14*, 297. https://doi.org/10.3390/agronomy14020297

Academic Editor: Francesco Montemurro

Received: 21 December 2023
Revised: 20 January 2024
Accepted: 26 January 2024
Published: 29 January 2024

1. Introduction

Cabbage (*Brassica oleracea* L. var. *capitata*) is a biennial vegetable species grown as an annual crop in different seasons of the year [1–3]. This vegetable is predominantly consumed in salads, pickles and cooked dishes [1,3]. Its high nutritional value [1] is attributed to the presence of several glucosinolates, including sinigrin, glucoraphanin, gluconapin, glucoerucin and progoitrin, which are found in the leaves [2,4,5]. The glucosinolates glucoraphanin and glucoerucin contained in cabbage are hydrolyzed by the enzyme myrosinase to produce the isothiocyanates sulforaphane and erucin, compounds that have been shown to possess anticarcinogenic activity [4]. Additionally, cabbage is rich in flavonoids like kaempferol, quercetin and apigenin, as well as vitamin C [6,7].

Cabbage is a widely cultivated vegetable around the world. According to the FAO statistical database, in 2021, the global cabbage cultivation was 2,450,601 hectares, with Europe contributing 305,603 hectares [8]. The corresponding cabbage yields were 29,261 kg ha^{-1} and 30,411 kg ha^{-1} for global and European production, respectively [8]. According to the FAO [8], in 2021, an increase of 24% in cabbage crop yield in Europe was recorded when compared to yield data recorded in 1990. This increase in yield has been attributed to the cultivation of cabbage hybrids that have been developed to differ in various traits, such as head shape (round, drum and pointed), leaf color (green, dark green and red or purple), head size and yield potential [1,9]. Cabbage yields typically range from 14.2 t ha^{-1} to 139.2 t ha^{-1}. This wide variation in yield is mainly attributed to the specific hybrid cultivated and the applied management practices, such as plant spacing, growing season and fertilization [9–13].

Meeting the nutrient requirements of cabbage is essential for achieving a high yield and product quality, as it is a highly demanding vegetable crop for the main macronutrients nitrogen (N), phosphorus (P) and potassium (K). Research by Lopandić and Zarić [14] showed that, by applying 240 kg ha^{-1} N, 140 kg ha^{-1} P and 210 kg ha^{-1} K, a high crop yield can be obtained. Similarly, Rosen et al. [15] found that the application of 250 kg ha^{-1} N increased the cabbage yield by 17% compared to a low nitrogen rate of 125 kg ha^{-1} N. In another study, Cui et al. [7] reported that the application of the inorganic fertilizer N-P-K (15-6.5-12.4) increased the cabbage yield by 18.3% compared to a control treatment in which no N was applied, and the combined application of inorganic fertilizer with organic fertilizer further increased the crop yield. In an experiment conducted in Brazil, the application of 150 kg ha^{-1} N, 100 kg ha^{-1} P_2O_5 and 100 kg ha^{-1} K_2O increased the cabbage yield by 45.6% compared to the control treatment [16].

Crop rotation is considered one of the most important agricultural cultivation practices that contribute to increased soil fertility and crop productivity through an improved N supply and reduced pest and weed pressure [17–20]. Continuous vegetable cropping is commonly associated with decreased productivity in several crops of high economic importance, such as Chinese cabbage, potato and tomato [19,21,22]. Feng et al. [22] reported a yield decrease in tomato of up to 46% in a monoculture system compared to rotations with other crops (e.g., eggplant). One of the most important factors that determines the success of crop rotation is the selection of the species to be included in the applied scheme. The incorporation of legume species such as pea and faba bean in rotation schemes has proven to be highly beneficial to both crop productivity and soil fertility through the improvement of organic C and total N content, available P and K, bulk density and cation exchange capacity [23–26]. Indeed, Shi et al. [25] reported a decline in the total N and C contents in a continuous potato cropping system compared to a crop rotation system of potato–pea. Similarly, the inclusion of faba bean in rotation schemes significantly increases both total N and C compared to non-legume rotation schemes [23]. It is also important to highlight that, in organic farming, in a cropping system with N limitations, the inclusion of legumes in the rotation scheme is an important N source due to their ability to fix nitrogen from the atmosphere [18,27–29]. Besides the increased yield in subsequent crops [30] and soil N enhancement that could lead to reduced dependency on N fertilizers, the incorporation of legumes into cropping systems can be beneficial to a wide range of ecological and human health perspectives. Indeed, the ecosystem services of legumes range from reductions in greenhouse gas emissions [31], plant-parasitic nematode and weed management [32,33], biodiversity conservation [34], sustainable intensification, which is of paramount importance for smallholder agriculture viability [35], and increased feed and forage self-sufficiency [36]. Moreover, the increased use of legume-derived products (e.g., protein) can lead to more healthy and sustainable diets [37,38].

Taking the above into consideration, a study was designed to evaluate the impact of crop rotation with cabbage, pea or faba bean on cabbage yield in both organic and conventional farming practices. The effects of the applied preceding crop (faba bean, pea or cabbage) and the fertilization scheme (organic or conventional) on soil fertility (N, P, K, NO_3^--N and NH_4^+-N) and nutrient content (N, P, and K) in the head tissues of cabbage plants were also assessed.

2. Materials and Methods

2.1. Site Description

Two field experiments (1st experiment: October 2015–March 2016; 2nd experiment: September 2016–February 2017) with cabbage as the main crop were conducted at the experimental farm of the Agricultural University of Athens in the Kopais region, located in central Greece (23°0504100′ E, 38°2305100′ N, altitude 95 m). The soil was silty clay in texture (clay: 43.7%, silt: 25.6%, and sand: 30.7%) with a pH of 8.1, EC (electrical conductivity) of 0.74 mS cm^{-1} and organic matter of 10.79%, and the total N, P, and the K content in the soil prior to the experiments' establishment (October 2014) were 0.27%, 28 mg kg^{-1} and 137 mg kg^{-1}, respectively [30]. The mean monthly air temperatures and precipitation during the two growing seasons of cabbage crop are given in our study by Yfantopoulos [39].

2.2. Experimental Design

The two field experiments were conducted according to a split-plot design with four replications and two experimental factors (farming system and rotation scheme). The farming system (organic or conventional) was the main plot factor, and the rotation scheme was the sub-plot factor. The preceding crops used in this study were pea (P), faba bean (F) and cabbage (C), and thus, the rotation treatments were as follows: P-C, F-C and C-C. The landraces 'AUAANDRO001' and 'AUALEFKADAfb001' of Greek origin were chosen for pea and faba bean, respectively, and the hybrid 'Krautkaiser F1′ was selected for the cabbage crop. The size of each sub-plot was 10.5 m^2 (3 × 3.5 m), and the transplanting rate of the cabbage crop was 40 × 40 cm.

Cabbage seedlings were transplanted at the stage of 3 to 4 leaves on 30 October 2015 and on 19 September 2016. Moreover, legume sowing took place on 20 November 2014 and 12 November 2015, and cabbage cultivation, used as the preceding crop, was established on 15 November 2014. Prior to cabbage transplanting, the inorganic NPK fertilizer 11-15-15 (N-P_2O_5-K_2O) was applied in the amount of 1.904 kg ha^{-1} in the conventional system, whereas dry sheep manure in the amount of 19.04 t ha^{-1} was applied in the organic farming system. The total N, P_2O_5, K_2O, CaO and MgO contents in the sheep manure were 0.84%, 0.3%, 0.7%, 0.38% and 0.24%, respectively, as reported in our previous study [39]. Also, in the 2nd experiment season, a top-dressing application of fertilizers was performed at the end of November 2016. More specifically, 476.19 kg ha^{-1} of an inorganic water-soluble fertilizer (20-20-20; N-P_2O_5-K_2O) and 952.19 kg ha^{-1} of an organic fertilizer (7-4-7 + 0.2; N-P_2O_5-K_2O + B) were applied in the conventional and the organic farming systems, respectively. In both farming systems, weeds in cabbage plots were controlled via hand hoeing, which was performed at 30 and 60 days after transplanting, and no herbicides were applied.

2.3. Growth and Yield of Cabbage Crop

To determine the head fresh weight, head dry weight, dry matter content (DMC) and cabbage head yield, sixteen plants from each sub-plot were selected, avoiding border plants. For the measurement of the head dry weight and dry matter content, samples from collected heads were dried in an oven at 65 °C to a constant weight. Harvesting was conducted at the end of March and February in 2016 and 2017, respectively.

2.4. Nutrient Contents in Soil and Cabbage Plant Tissues

Soil samples were collected using a cylindrical auger (diameter: 10 cm, length: 20 cm) prior to cabbage establishment (PCE), in the intermediate growth stage of cabbage (IS) and at the harvest stage (HS). The soil samples were dried and then sieved using a 2 mm stainless sieve. The contents of NO_3^--N and NH_4^+-N, P and K in the soil samples were determined following the methods described by Ntatsi et al. [40,41] and Yfantopoulos et al. [39]. For the determination of the total N (%) in the soil, samples were collected prior to cabbage transplanting (PCE) and at the harvest stage (HS). The soil samples were air-dried and sieved using a stainless sieve (<0.14 mm) before the analysis via the Kjeldahl method.

For the determination of the N, P and K contents in the cabbage dry head tissues, samples were collected at the final harvest stage and dried in a forced-air oven at 65 °C to a constant weight. Then, the samples were ground to a powder using a suitable laboratory mill. Moreover, for P and K determination, the plant samples were first dry-ashed (550 °C) and then extracted with hydrogen chloride (HCl, 1 N). The Kjeldahl method was applied for N determination. Moreover, the P content was determined using a microplate spectrophotometer (Anthos Zenyth 200; Biochrom, Holliston, MA 01746-1388, USA), whereas the K content was determined via flame photometry (Sherwood Model 410, Cambridge, UK).

2.5. Statistical Analysis

To evaluate the effects of the farming system (main factor) and preceding crop (subplot factor), as well as the interactions between them, a two-factorial analysis of variance (ANOVA) was performed using the STATISTICA software package, version 9.0 for Windows (StatSoft Inc., Tulsa, OK, USA). After the analysis of variance, the means of all evaluated parameters (cabbage and soil) were compared using Duncan's multiple range test at $p \leq 0.05$.

3. Results

3.1. Cabbage Growth

In the first growing season, a significant interaction between the farming system and the rotation scheme was found for the head fresh and dry weight, with the lowest values recorded in the organic C-C plots. The fresh and dry weights of the heads were affected by the farming system and the rotation scheme. More specifically, higher head fresh weights and dry weights were recorded in the conventionally grown plots compared to the organically grown plots. Regarding the rotation scheme, higher head fresh and dry weights were recorded when faba bean and pea were the preceding crops compared to the C-C treatment (Table 1). Moreover, in the second growing season, the application of organic fertilization resulted in decreased fresh and dry head weights by 14.2% and 17.6%, respectively, compared to the conventional farming system. No interaction among the applied treatments were found, and the impact of the rotation scheme was insignificant for the two above-mentioned growth parameters (Table 2).

The dry matter content (DMC) of the heads, estimated at the harvest stage, was unaffected by the treatments applied and ranged from 8.17% to 8.83% in the first growing season and from 8.62% to 9.13% in the second growing season.

3.2. Cabbage Head Yield

The statistical analysis of the head yield in the cabbage crop revealed significant interactions between the farming system and the rotation scheme applied. Specifically, in both growing seasons, the lowest head yield was recorded in plots where cabbage was cultivated as the preceding crop under the organic farming system (57 t ha^{-1} and 53.87 t ha^{-1} in 2015/2016 and 2016/2017, respectively) (Table 3). Moreover, in the conventional system, there were no statistically significant differences between the preceding crop treatments, and the cabbage head yield ranged from 67.06 to 73.12 t ha^{-1}. In the organic farming system, the increase in the cabbage head yield reached up to 21.1% when pea was the preceding crop compared to the C-C treatment.

3.3. Soil Nitrate, Ammonium and Total Nitrogen Content

In 2015/2016, prior to cabbage transplanting (PCE) and at the intermediate growth stage (IS) of cabbage, the highest soil NO_3^--N content was recorded in the conventional farming system plots where pea was the preceding crop. However, no significant differences were observed at the harvest stage of the cabbage crop among the treatments applied. In the case of the ammonium (NH_4^+-N) content in the soil, our results show that both the farming system and preceding crop had no impact on this parameter. The ammonium content in the soil ranged from 4.7 to 6.0 mg kg^{-1} (Table 4).

Table 1. Impact of the farming system (FS) (organic or conventional) and crop rotation scheme (RS) (cabbage, pea and faba bean: C, P and F, respectively) on the cabbage head fresh weight, head dry weight and dry matter content (DMC) at the harvest stage in the 1st experiment.

Farming System	Rotation Scheme	1st Experiment: 2015–2016		
		Head Fresh Weight (g $head^{-1}$)	Head Dry Weight (g $head^{-1}$)	DMC (%)
Organic	C-C	912 b	77.61 b	8.51
	P-C	1082 ab	89.56 ab	8.28
	F-C	1046 ab	85.86 ab	8.21
Conventional	C-C	1159 a	94.72 a	8.17
	P-C	1073 ab	94.77 a	8.83
	F-C	1156 a	98.98 a	8.56
Main effects				
Organic		1013	84.34	8.33
Conventional		1129	96.16	8.52
	C-C	1036	86.17	8.32
	P-C	1078	92.17	8.55
	F-C	1101	92.42	8.39
Statistical significance				
Farming system (FS)		*	**	ns
Rotation scheme (RS)		*	*	ns
FS × RS		*	*	ns

Means (n = 4) followed by different letters within the same column indicate significant differences for each factor according to Duncan's multiple range test. * and **, significant at $p < 0.05$ and $p < 0.01$, respectively. ns = non-significant.

Table 2. Impact of the farming system (organic or conventional) and crop rotation scheme (RS) (cabbage, pea and faba bean: C, P and F, respectively) on the cabbage head fresh weight, head dry weight and dry matter content (DMC) at the harvest stage in the 2nd experiment.

Farming System	Rotation Scheme	2nd Experiment: 2016–2017		
		Head Fresh Weight (g $head^{-1}$)	Head Dry Weight (g $head^{-1}$)	DMC (%)
Main effects				
Organic		995.31	86.18	8.66
Conventional		1159.70	104.65	9.02
	C-C	1007.95	92.08	9.13
	P-C	1100.20	97.20	8.84
	F-C	1124.37	96.97	8.62
Statistical significance				
Farming system (FS)		*	***	ns
Rotation scheme (RS)		ns	ns	ns
FS × RS		ns	ns	ns

Means (n = 4) followed by different letters within the same column indicate significant differences for each factor according to Duncan's multiple range test. * and ***, significant at $p < 0.05$ and $p < 0.001$, respectively. ns = non-significant.

In 2016/2017, the NO_3^--N content in three cropping stages was significantly higher in the conventional farming system compared to that in the organic farming system. Regarding the impact of the preceding crop used in the rotation scheme, our results indicate that the C-C treatment significantly reduced the NO_3^--N soil content compared to both legumes used in the rotation scheme. Regarding the second growing season, the NH_4^+-N content was lower only during the intermediate growth stage (IS) when plants were grown under organic farming practices. No significant interaction was found for the treatments applied (Table 5).

Table 3. Impact of the farming system (organic or conventional) and crop rotation scheme (RS) (cabbage, pea and faba bean: C, P and F, respectively) on the cabbage total head yield (t ha^{-1}) in two experimental seasons.

Farming System	Rotation Scheme	Total Head Yield (t ha^{-1})	
		2015–2016	2016–2017
Organic	C-C	57.00 c	53.87 d
	P-C	67.63 b	64.31 c
	F-C	65.38 b	68.31 b
Conventional	C-C	72.44 a	72.06 a
	P-C	67.06 b	73.12 a
	F-C	72.25 a	72.18 a
Main effects			
Organic		63.33	62.16
Conventional		70.58	72.45
	C-C	64.72	62.96
	P-C	67.34	68.71
	F-C	68.81	70.25
Statistical significance			
Farming system (FS)		***	***
Rotation scheme (RS)		**	***
FS × RS		***	***

Means (n = 4) followed by different letters within the same column indicate significant differences for each factor according to Duncan's multiple range test. ** and ***, significant at $p < 0.01$ and $p < 0.001$, respectively.

Table 4. Impact of the farming system (organic or conventional) and crop rotation scheme (RS) (cabbage, pea and faba bean: C, P and F, respectively) on soil NO_3^--N and NH_4^+-N concentrations prior to crop establishment (PCE), in the intermediate growth stage (IS) and at the harvest stage (HS) of the cabbage crop in the 1st experimental season.

Farming System	Rotation Scheme	NO_3^--N (mg kg^{-1})			NH_4^+-N (mg kg^{-1})		
		PCE	IS	HS	PCE	IS	HS
Organic	C-C	13.9 b	14.7	14.6	4.7	5.3	5.2
	P-C	14.7 b	16.1	15.4	5.5	5.9	5.8
	F-C	15.1 b	16.8	15.6	5.3	5.9	5.8
Conventional	C-C	14.4 b	15.6	15.3	5.2	5.7	5.4
	P-C	19.3 a	19.9	19.0	5.3	5.9	5.3
	F-C	15.2 b	15.7	15.2	5.8	6.0	5.7
Main effects							
Organic		14.6	15.9	15.2	5.2	5.7	5.6
Conventional		16.3	17.1	16.5	5.4	5.9	5.5
	C-C	14.2	15.2 b	15.0	5.0	5.5	5.3
	P-C	17.0	18.0 a	17.2	5.4	5.9	5.6
	F-C	15.2	16.3 ab	15.4	5.6	6.0	5.8
Statistical significance							
Farming system (FS)		**	ns	ns	ns	ns	ns
Rotation scheme (RS)		**	*	ns	ns	ns	ns
FS × RS		*	ns	ns	ns	ns	ns

Means (n = 4) followed by different letters within the same column indicate significant differences for each factor according to Duncan's multiple range test. * and **, significant at $p < 0.05$ and $p < 0.01$, respectively. ns = non-significant.

Table 5. Impact of the farming system (FS) (organic or conventional) and crop rotation scheme (RS) (cabbage, pea and faba bean: C, P and F, respectively) on soil NO_3^--N and NH_4^+-N contents prior to crop establishment (PCE), in the intermediate growth stage (IS) and at the harvest stage (HS) of the cabbage crop in the 2nd experimental season.

Farming System	Rotation Scheme	NO_3^--N (mg kg^{-1} DW)			NH_4^+-N (mg kg^{-1} DW)		
		PCE	IS	HS	PCE	IS	HS
Organic		14.3	14.2	14.0	4.3	4.0	3.9
Conventional		15.3	15.4	15.0	4.9	4.8	4.5
	C-C	13.7 c	13.6 b	13.4 b	4.6	4.5	4.1
	P-C	15.6 a	15.5 a	14.9 ab	4.7	4.6	4.5
	F-C	15.2 b	15.2 ab	15.2 a	4.6	4.2	4.1
Statistical significance							
Farming system (FS)		*	*	**	ns	*	ns
Rotation scheme (RS)		***	*	***	ns	ns	ns
FS × RS		ns	ns	ns	ns	ns	ns

Means (n = 4) followed by different letters within the same column indicate significant differences for each factor according to Duncan's multiple range test. *, ** and ***, significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively. ns = non-significant.

In both growing seasons and for all sampling stages, significantly higher soil total N levels were recorded when faba bean and pea were the preceding crops compared to cabbage. Moreover, no differences among the different legumes used in this study were recorded. In the second growing season, in both crop stages (PCE and HS), the soil total N levels were significantly higher in the organic farming system, and in the first growing season, no significant differences between the two farming systems were recorded (Table 6).

Table 6. Impact of the farming system (FS) (organic or conventional) and crop rotation scheme (RS) (cabbage, pea and faba bean: C, P and F, respectively) on the soil total N (%) content prior to crop establishment (PCE) and at the harvest stage (HS) of the cabbage crop in two experimental seasons.

Farming System	Rotation Scheme	Soil Total N (%)			
		2015–2016		2016–2017	
		PCE	HS	PCE	HS
Organic	C-C	0.446	0.491 c	0.528	0.525
	P-C	0.481	0.546 a	0.566	0.554
	F-C	0.494	0.548 a	0.539	0.557
Conventional	C-C	0.437	0.514 b	0.508	0.529
	P-C	0.519	0.533 ab	0.527	0.525
	F-C	0.511	0.531 ab	0.550	0.542
Main effects					
Organic		0.474	0.528	0.544 a	0.545 a
Conventional		0.489	0.526	0.528 b	0.532 b
C-C		0.442 b	0.503	0.518 b	0.527 b
P-C		0.500 a	0.540	0.547 a	0.540 ab
F-C		0.503 a	0.539	0.545 a	0.550 a
Statistical significance					
Farming system (FS)		ns	ns	*	*
Rotation scheme (RS)		**	***	*	**
FS × RS		ns	*	ns	ns

Means (n = 4) followed by different letters within the same column indicate significant differences for each factor according to Duncan's multiple range test. *, ** and ***, significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively. ns = non-significant.

3.4. Soil Phosphorus and Potassium Contents

In both experimental seasons, the soil P content was higher in the conventional farming system compared to that in the organic farming system (Table 7). More specifically, the P content increased up to 26.5% and 25.6% in 2015/2016 and 2016/2017, respectively. The impact of the rotation scheme applied was insignificant, and no interaction among the tested parameters was recorded.

Table 7. Impact of the farming system (organic or conventional) and crop rotation scheme (RS) (cabbage, pea and faba bean: C, P and F, respectively) on soil P content prior to crop establishment (PCE), in the intermediate growth stage (IS) and at the harvest stage (HS) of the cabbage crop in two experimental seasons.

Farming System	Rotation Scheme	P (mg kg^{-1})					
		2015–2016			2016–2017		
		PCE	IS	HS	PCE	IS	HS
Main effects							
Organic		43.0 b	54.5 b	41.1 b	52.1 b	58.1	37.1 b
Conventional		58.5 a	63.7 a	53.1 a	63.1 a	57.0	49.9 a
	C-C	50.4	62.1	44.9	58.1	57.5	42.8
	P-C	51.7	57.5	48.6	54.3	56.4	45.5
	F-C	50.2	57.6	47.8	60.4	58.8	42.2
Statistical significance							
Farming system (FS)		*	*	*	*	ns	***
Rotation scheme (RS)		ns	ns	ns	ns	ns	ns
FS × RS		ns	ns	ns	ns	ns	ns

Means (n = 4) followed by different letters within the same column indicate significant differences for each factor according to Duncan's multiple range test. * and ***, significant at $p < 0.05$ and $p < 0.001$, respectively. ns = non-significant.

In the case of the soil potassium content, the highest values were recorded in conventional farming systems in both seasons prior to crop establishment. Among the preceding crop treatments, a higher K content was measured in cabbage monocrop plots. The K content ranged from 132 mg kg^{-1} to 178 mg kg^{-1} and from 139 mg kg^{-1} to 178 mg kg^{-1} in 2015/2016 and 2016/2017, respectively. In the second sampling stage (IS), the K content was lower compared to that in the first sampling date. Moreover, at the final harvest stage, in the first growing season, both factors affected the K content, with the highest values recorded in the conventional farming systems and in the C-C treatment. In the second growing season, no significant differences among the three preceding crop treatments were found (Table 8). Finally, at the harvest stage, the K content in all treatments ranged from 107 mg kg^{-1} to 121 mg kg^{-1} and from 107 mg kg^{-1} to 126 mg kg^{-1} in 2015/2016 and 2016/2017, respectively. These values were lower than those recorded at the intermediate growth stage of cabbage.

3.5. Nutrient Content in Cabbage Head Tissues

In both experimental seasons, the total N, P and K contents in cabbage heads were affected only by the farming system (Table 9). More specifically, the total N value was higher in the conventional system by 13.3% and 8.6% in 2015/2016 and 2016/2017, respectively. Moreover, the conventional farming system increased the P and K contents in cabbage heads by up to 39.7% and 21.6%, respectively. The nutrient content in cabbage head tissue was not affected by the rotation scheme.

Table 8. Impact of the farming system (organic or conventional) and crop rotation scheme (RS) (cabbage, pea and faba bean: C, P and F, respectively) on soil K content (mg kg^{-1}) prior to crop establishment (PCE), in the intermediate growth stage (IS) and at the harvest stage (HS) of the cabbage crop in two experimental seasons.

Farming System	Rotation Scheme	K (mg kg^{-1} DW)					
		2015–2016			2016–2017		
		PCE	IS	HS	PCE	IS	HS
Organic	C-C	142	136 c	114	150	131	109
	P-C	132	128 d	107	139	125	111
	F-C	133	126 d	108	139	121	107
Conventional	C-C	178	159 a	121	178	155	126
	P-C	173	143 b	116	170	145	120
	F-C	168	136 c	117	168	136	115
Main effects							
Organic		136 b	130	110	143 b	126 b	109 b
Conventional		173 a	146	118	172 a	145 a	120 a
	C-C	160 a	148	118 a	164 a	143 a	118
	P-C	153 b	136	112 b	155 b	135 b	116
	F-C	151 b	131	113 b	154 b	129 c	111
Statistical significance							
Farming system (FS)		***	***	***	***	***	***
Rotation scheme (RS)		***	***	**	***	***	ns
FS × RS		ns	*	ns	ns	ns	ns

Means (n = 4) followed by different letters within the same column indicate significant differences for each factor according to Duncan's multiple range test. *, ** and ***, significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$, respectively. ns = non-significant.

Table 9. Impact of the farming system (organic or conventional) on total N (%), P (%) and K (%) contents in cabbage heads (dry basis) at the harvest stage in two experimental seasons.

Farming System	Rotation Scheme	2015–2016			2016–2017		
		N (%)	P (%)	K (%)	N (%)	P (%)	K (%)
Main effects							
Organic		3.13 b	0.46 b	2.33 b	3.07 b	0.44 b	2.57 b
Conventional		3.61 a	0.75 a	2.85 a	3.36 a	0.73 a	3.28 a
	C-C	3.45	0.58	2.61	3.26	0.56	2.95
	P-C	3.28	0.56	2.54	3.16	0.54	2.84
	F-C	3.38	0.68	2.63	3.21	0.66	3.00
Statistical significance							
Farming system (FS)		*	***	***	*	***	***
Rotation scheme (RS)		ns	ns	ns	ns	ns	ns
FS × RS		ns	ns	ns	ns	ns	ns

Means (n = 4) followed by different letters within the same column indicate significant differences for each factor according to Duncan's multiple range test. * and ***, significant at $p < 0.05$ and $p < 0.001$, respectively. ns = non-significant.

4. Discussion

4.1. Nutrient Content in Soil

This study aimed to investigate the effects of the rotation scheme and farming system on soil NO_3^--N, NH_4^+-N, total N, P and K during two growing seasons. The results show that the NH_4^+-N content in the soil was not affected by the farming system and/or the rotation scheme applied. It is important to highlight that the NH_4^+-N content in the soil was higher at the intermediate growth stage of cabbage compared to that at the harvest stage. A similar trend was also found for the NO_3^--N, P and K contents. These results clearly indicate that NO_3^-, NH_4^+, P and K uptake is higher during the head formation stage of cabbage, thereby leading to a reduced concentration in the soil. Hara and Sonoda [42] reported that nutrient content in plants significantly affects head formation, and consequently, the head yield may be reduced by 50% when the contents of N, P and K in the outer leaves are 1.3%, 0.1% and 0.3%, respectively.

In the present study, the use of inorganic fertilization led to a significant increase in the soil NO_3^-, NH_4^+, P and K compared to organic fertilization. These results are consistent with the study by Duarte et al. [12], who found that the application of 80 kg P_2O_5 ha^{-1} increased P by 75.9% in the soil samples collected from a cabbage crop at site 1 and by 29.6% at site 2. By comparing the contents of soil NO_3^-, NH_4^+, total N, P and K at the harvest stage with the corresponding values prior to the establishment of the crop, a reduction was found. In agreement with the above, Atanasova et al. [43] found a decrease in NO_3^-, NH_4^+, total N and K contents in the soil after cabbage harvesting, whereas the reverse was the case for P. By comparing the nutrient levels in the plots in which inorganic fertilization was applied (N-P_2O_5-K_2O; 150 kg ha^{-1}, 100 kg ha^{-1} and 100 kg ha^{-1}) with those receiving organic fertilizers (farmyard manure at a rate of 24 t ha^{-1}), Atanasova et al. [43] found that farmyard manure application led to the soil NO_3^-, NH_4^+, total N and P contents increasing, and no significant differences in the soil K content were found.

The results of the present study demonstrate that crop rotation can significantly impact the levels of soil NO_3^-, total N and K but not NH_4^+ and P soil contents. It is also important to point out that, in the conventional farming system, the three rotation schemes resulted in an increase in soil P and K contents compared to their initial levels of 28 mg kg^{-1} and 137 mg kg^{-1}, respectively. This increase can be attributed to the application of high rates of inorganic fertilizers and the incorporation of pea and faba bean into the soil. According to Ma et al. [26], green manure application could result in increased available P and K soil contents when compared to fallow soil. Similar results for soil N, P and K contents were found with the incorporation of green manure originating from *Vigna unguiculata* L. Walp. [44]. However, the benefits of crop rotation to soil fertility and plant performance are species-dependent, with faba bean proving superior to field pea in crop rotation with broccoli or cauliflower, a result attributed to differences in soil N, P and K contents [45].

It is evident from the present study that legumes like field pea and faba bean were effective in increasing soil N levels, likely due to their ability to fix atmospheric nitrogen. This is supported by Stein et al. [46], who reported that pea and faba bean crops fixed 156 kg ha^{-1} and 195 kg ha^{-1}, respectively. On the other hand, cabbage cultivation for two consecutive years led to lower NO_3^- and total N in the soil, since, as mentioned above, this crop had high demands for N. According to Ma et al. [26], legume green manure application increased soil NO_3^--N content by 50% when compared to the fallow control treatment. In contrast to the N content in the soil, continuous cultivation of cabbage (C-C) increased the soil K content compared to the other two rotation schemes applied. This increase in K content is ascribed to the high rates of K application in the conventional farming system compared to the organic farming system (285.6 kg K_2O ha^{-1} vs. 130 kg K_2O ha^{-1}).

Overall, this study suggests the combined application of inorganic fertilization and the inclusion of legumes in rotation schemes as an agronomic management practice that could contribute to improved soil fertility with subsequent benefits to the following cabbage crop.

4.2. Nutrient Content in Head Tissues

The N content in cabbage heads at the harvest stage varies between the growing seasons and ranges from 1.94% to 2.88%, as reported by Rosen et al. [15], and Duarte et al. [12] found that the P content in cabbage leaves ranges from 0.19 to 0.82%. In the present study, the total N content in cabbage tissues ranged from 3.07% to 3.61%, and the P and K contents ranged from 0.44% to 0.75% and from 2.33% to 3.28%, respectively. Inthichack et al. [47] observed that K content is strongly correlated with the position of the leaf in the cabbage head since a lower K content was found in the 10th inner leaf (3.61% to 4.81%) compared to the outside leaf of the head (4.34% to 6.96%). However, a wide range of 0.32% to 5.03% of K was reported in the outer leaves of cabbage plants by Hara and Sonoda [42]. The findings of the present study offer valuable information on the nutritional composition of cabbage with practical implications for optimizing fertilizer application, which could result in increased productivity and quality.

In the present study, no significant differences in head tissues' nutrient contents between the preceding crops in both farming systems were found. This can be attributed to the high rates of inorganic and organic fertilizers. This is evident from the high N content in cabbage tissues, which were grown in highly fertile soil with organic matter of 10.79% and clay of 43.7%. Rosen et al. [15] demonstrated that doubling the N rate to 250 kg ha^{-1} resulted in a 17% increase in the N content in cabbage heads. Similarly, Duarte et al. [12] reported an increased P content in the leaves of this crop attributed to high P application, and Inthichack et al. [47] observed a positive correlation between the K fertilizer rate and K content in leaves. Our findings reveal significant differences in the total N, P and K contents between the two farming systems. Interestingly, the application of organic fertilizers resulted in lower values of these nutrients in both growing seasons. This can be attributed to the slow release of nutrients from organic fertilizers, particularly the manure used in this study. As Hartz et al. [48] reported, only 15% to 16% of organic nitrogen from the manure was mineralized after incubation at 25 °C and constant moisture for 12 and 24 weeks, respectively. This suggests that the use of organic fertilizers may not provide sufficient nutrients required for optimal cabbage growth and subsequent yield when compared to inorganic fertilizers. These findings should be taken into consideration when designing fertilization schemes, since the selection of the appropriate fertilizer type and application rate can result in improved nutrient contents without compromising environmental health.

4.3. Head Yield

Cabbage is a crop known for its high productivity, with yields often exceeding 130 t ha^{-1} [12]. However, in the present study, head yields ranged from 53.87 t ha^{-1} to 73.12 t ha^{-1} over two growing seasons. The ANOVA of our results revealed that both factors (rotation scheme and farming system) significantly affected the head yield, with an interaction between the two factors. Notably, in both growing seasons, the lowest yield was recorded in the C-C treatment under the organic farming system. This can be attributed to the high demands of the cabbage crop for N, P and K, as previously reported, in combination with the slow nutrient mineralization rate of the organic fertilizer. As a result, the plants' nutrient needs were not sufficiently met during head formation in this farming system. Typically, inorganic fertilization leads to higher head yields in the cabbage crop compared to organic fertilization. Consistent with this, Atanasova et al. [43] reported that the highest yield of cabbage was obtained in the inorganic fertilization treatment (N-P_2O_5-K_2O; 150 kg ha^{-1}, 100 kg ha^{-1}, and 100 kg ha^{-1}) compared to the farmyard manure treatment (24 t ha^{-1}). However, the combination of inorganic and organic fertilizers can result in higher or equal yields to inorganic fertilizer, depending on the ratio of inorganic to organic fertilizer [7].

Contrary to the organic farming system, in the conventional farming system, no statistical differences between the use of different species as the preceding crop were found, likely due to the high application rate of inorganic fertilizer 11-15-15, which covers the crops' needs for the macronutrients N, P and K. Also, in the organic farming system, no significant differences between pea and faba bean were recorded, since the two species exhibit a high nitrogen fixation ability and thus constitute a good N source for the subsequent crop. In 2015, prior to cabbage crop establishment, the amount of biologically fixed N from faba bean landrace AUALEFKADAfb001, which was subsequently incorporated into the soil, was 183,2 kg ha^{-1} (average of two farming systems), and in 2016, the fixed N of faba bean was 187.5 kg ha^{-1} (average of two farming systems) [40]. Similarly, the fixed N of pea landrace AUAANDRO001 was 69.1 kg ha^{-1} and 87.1 kg ha^{-1} in 2015 and 2016, respectively [41]. Stein et al. [46] observed that the incorporation of pea (156 kg ha^{-1}) and faba bean (195 kg ha^{-1}) into the soil significantly increased the head yield of the cabbage crop compared to control plots with bare soil or plots with rye (*Secale cereale* L.). Additionally, Sallaku et al. [45] reported that the use of pea and faba bean as preceding crops in rotation schemes with cauliflower and broccoli resulted in enhanced yields compared to the use of wheat as the preceding crop, a result mostly attributed to the increase in the total N, P and K contents in the soil.

As expected, the results for the head weight (fresh or dry) were similar to those obtained for the head yield, whereas the dry matter content at the harvest stage was not affected by either factor. It is important to highlight that the head fresh weight was low, ranging from 912 g to 1159.7 g. It is well documented that the planting date affects both the yield and head weight [49]. Indeed, early planting during summer (July and August) can result in heavier heads due to the promotion of photosynthesis and the subsequent production of assimilates. On the other hand, crop transplanting during fall (September or October) could lead to lighter heads with weights ranging from 1.34 to 1.42 kg [50].

5. Conclusions

In conclusion, our study revealed a strong relationship between the choice of the preceding crop in a rotation scheme, soil fertility and cabbage growth. The utilization of pea and faba bean as preceding crops resulted in increased levels of soil NO_3^--N and total N, attributed to the high nitrogen fixation ability of these legumes. Conversely, monocropping cabbage for two subsequent years (C-C) led to an increased soil K content due to the increased application of inorganic fertilizers. It is worth noting that no significant differences in the soil P content were found between the different preceding crops. Additionally, the use of inorganic fertilizer in the conventional farming systems led to significant differences in soil fertility. In the organic farming systems, a yield decrease was found for the head yield in the C-C treatment. This clearly demonstrates that the slow nutrient mineralization rate of organic fertilizers cannot meet the high nutrient demands of cabbage during head formation. This highlights the necessity of applying tailored fertilizers that meet crop requirements, thereby enhancing product quality, particularly nutrient content. In light of these findings, the optimization of cabbage production necessitates careful consideration of both the preceding crop and the farming system. Moreover, besides crop nutrient requirements, local climate conditions should also be taken into consideration when designing sustainable and efficient cabbage cultivation strategies.

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

Funding: This research was funded by the European Commission within the FP7 Research Project 'EUROLEGUME-Enhancing of legumes growing in Europe through sustainable cropping for protein supply for food and feed' (Grant Agreement No. 613781).

Data Availability Statement: Data are contained within the article.

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

References

1. Fang, Z.; Liu, Y.; Lou, P.; Liu, G. Current trends in cabbage breeding. *J. New Seeds* **2004**, *6*, 75–107. [CrossRef]
2. Choi, S.H.; Park, S.; Lim, Y.P.; Kim, S.-J.; Park, J.-T.; An, G. Metabolite profiles of glucosinolates in cabbage varieties (*Brassica oleracea* var. *capitata*) by season, color, and tissue position. *Hortic. Environ. Biotechnol.* **2014**, *55*, 237–247. [CrossRef]
3. Bhandari, S.R.; Choi, C.S.; Rhee, J.; Jo, J.S.; Shin, Y.K.; Song, J.W.; Lee, J.G. Seasonal variation in agronomic characteristics and sugar content of cabbage genotypes. *Chil. J. Agric. Res.* **2021**, *81*, 80–91. [CrossRef]

4. Kuljarachanan, T.; Fu, N.; Chiewchan, N.; Devahastin, S.; Chen, X.D. Evolution of important glucosinolates in three common: *Brassica* Vegetables during their processing into vegetable powder and in vitro gastric digestion. *Food Funct.* **2020**, *11*, 211–220. [CrossRef] [PubMed]
5. Oloyede, O.O.; Wagstaff, C.; Methven, L. The impact of domestic cooking methods on myrosinase stability, glucosinolates and their hydrolysis products in different cabbage (*Brassica oleracea*) accessions. *Foods* **2021**, *10*, 2908. [CrossRef] [PubMed]
6. Chun, O.K.; Smith, N.; Sakagawa, A.; Lee, C.Y. Antioxidant properties of raw and processed cabbages. *Int. J. Food Sci. Nutr.* **2004**, *55*, 191–199. [CrossRef] [PubMed]
7. Cui, X.; Lu, H.; Lu, Y.; Gao, P.; Peng, F. Replacing 30% chemical fertilizer with organic fertilizer increases the fertilizer efficiency, yield and quality of cabbage in intensive open-field production. *Cienc. Rural* **2022**, *52*, e20210186. [CrossRef]
8. FAO. Food and Agriculture Organization of the United Unions. *FAOSTAT. Food and Agriculture Data.* Available online: https://www.fao.org/faostat/en/#data/QCL (accessed on 22 April 2023).
9. Červenski, J.; Gvozdanović-Varga, J.; Vasić, M.; Glogovac, S. Multivariate analysis for head weight and yield performance of experimental cabbage hybrids (*Brassica oleracea* var. *capitata* L.). *Genetika* **2010**, *42*, 259–266. [CrossRef]
10. Stoleru, V.V.; Munteanu, N.C.; Stoleru, C.M.V.; Rotaru, L.G. Cultivar selection and pest control techniques on organic white cabbage yield. *Not. Bot. Horti Agrobo.* **2012**, *40*, 190–196. [CrossRef]
11. Islam, M.A.; Ferdous, G.; Akter, A.; Hossain, M.M.; Nandwani, D. Effect of organic, inorganic fertilizers and plant spacing on the growth and yield of cabbage. *Agriculture* **2017**, *7*, 31. [CrossRef]
12. Duarte, L.O.; de Aquino, L.A.; Caixeta, I.A.B.; Gonçalves, F.A.R.; Dos Reis, M.R. Rates and methods of phosphorus application in cabbage crop. *Pesqui. Agropecu. Trop.* **2019**, *49*, e54191. [CrossRef]
13. Kacjan Maršić, N.; Može, K.S.; Mihelič, R.; Nečemer, M.; Hudina, M.; Jakopič, J. Nitrogen and sulphur fertilisation for marketable yields of cabbage (*Brassica oleracea* L. var. *capitata*), leaf nitrate and glucosinolates and nitrogen losses studied in a field experiment in central Slovenia. *Plants* **2021**, *10*, 1304. [CrossRef]
14. Lopandić, D.; Zarić, D. The effect of nitrogen aates and application dates on cabbage (cv. Bijeljinski) yield. *Acta Hortic.* **1997**, *462*, 595–598. [CrossRef]
15. Rosen, C.J.; Fritz, V.A.; Gardner, G.M.; Hecht, S.S.; Carmella, S.G.; Kenney, P.M. Cabbage yield and glucosinolate concentrations as affected by nitrogen and sulfur fertility. *HortScience* **2005**, *40*, 1493–1498. [CrossRef]
16. Torres, J.L.R.; Gomes, F.R.C.; Barreto, A.C.; Tamburús, A.Y.; Vieira, D.M.S.; Souza, Z.M.; Mazetto, J.C. Application of different cover crops and mineral fertilizer doses for no-till cultivation of broccoli, cauliflower and cabbage. *Aust. J. Crop Sci.* **2017**, *11*, 1339–1345. [CrossRef]
17. Dillard, H.R.; Bellinder, R.R.; Shah, D.A. Integrated management of weeds and diseases in a cabbage cropping system. *Crop Prot.* **2004**, *23*, 163–168. [CrossRef]
18. Karavidas, I.; Ntatsi, G.; Ntanasi, T.; Vlachos, I.; Tampakaki, A.; Iannetta, P.P.M.; Savvas, D. Comparative assessment of different crop rotation schemes for organic common bean production. *Agronomy* **2020**, *10*, 1269. [CrossRef]
19. Bak, G.-R.; Lee, G.-J.; Lee, J.-T.; Jee, S.-N. Crop rotation affects biological properties of rhizosphere soil and productivity of kimchi cabbage (*Brassica rapa* ssp. *pekinensis*) compared to monoculture. *Hortic. Environ. Biotechnol.* **2022**, *63*, 613–625. [CrossRef]
20. Li, Q.-M.; Zhang, D.; Zhang, J.-Z.; Zhou, Z.-J.; Pan, Y.; Yang, Z.-H.; Zhu, J.-H.; Liu, Y.-H.; Zhang, L.-F. Crop rotations increased soil ecosystem multifunctionality by improving keystone taxa and soil properties in potatoes. *Front. Microbiol.* **2023**, *14*, 1034761. [CrossRef]
21. Qin, S.; Yeboah, S.; Cao, L.; Zhang, J.; Shi, S.; Liu, Y. Breaking continuous potato cropping with legumes improves soil microbial communities, enzyme activities and tuber yield. *PLoS ONE* **2017**, *12*, e0175934. [CrossRef]
22. Feng, C.; Yi, Z.; Qian, W.; Liu, H.; Jiang, X. Rotations improve the diversity of rhizosphere soil bacterial communities, enzyme activities and tomato yield. *PLoS ONE* **2023**, *18*, e0270944. [CrossRef]
23. Aschi, A.; Aubert, M.; Riah-Anglet, W.; Nélieu, S.; Dubois, C.; Akpa-Vinceslas, M.; Trinsoutrot-Gattin, I. Introduction of faba bean in crop rotation: Impacts on soil chemical and biological characteristics. *Appl. Soil Ecol.* **2017**, *120*, 219–228. [CrossRef]
24. Karkanis, A.; Ntatsi, G.; Kontopoulou, C.-G.; Pristeri, A.; Bilalis, D.; Savvas, D. Field pea in European cropping systems: Adaptability, biological nitrogen fixation and cultivation practices. *Not. Bot. Horti Agrobo.* **2016**, *44*, 325–336. [CrossRef]
25. Shi, M.; Guo, A.; Kang, Y.; Yang, X.; Zhang, W.; Liu, Y.; Zhang, R.; Wang, Y.; Qin, S. Effects of plastic film mulching and legume rotation on soil nutrients and microbial communities in the Loess Plateau of China. *Chem. Biol. Technol. Agric.* **2023**, *10*, 38. [CrossRef]
26. Ma, D.; Lina Yin, L.; Ju, W.; Li, X.; Liu, X.; Deng, X.; Shiwen Wang, S. Meta-analysis of green manure effects on soil properties and crop yield in northern China. *Field Crops Res.* **2021**, *266*, 108146. [CrossRef]
27. Katroschan, K.-U.; Stützel, H. Narrow-leaved lupine as an N source alternative to grass-clover swards in organic vegetable rotations. *Biol. Agric. Hortic.* **2017**, *33*, 125–142. [CrossRef]
28. Perrone, S.; Grossman, J.; Liebman, A.; Sooksa-nguan, T.; Gutknecht, J. Nitrogen fixation and productivity of winter annual legume cover crops in Upper Midwest organic cropping systems. *Nutr. Cycl. Agroecosyst.* **2020**, *117*, 61–76. [CrossRef]
29. Barbieri, P.; Starck, T.; Voisin, A.-S.; Nesme, T. Biological nitrogen fixation of legumes crops under organic farming as driven by cropping management: A review. *Agric. Syst.* **2023**, *205*, 103579. [CrossRef]
30. Geng, S.; Tan, J.; Li, L.; Miao, Y.; Wang, Y. Legumes can increase the yield of subsequent wheat with or without grain harvesting compared to Gramineae crops: A meta-analysis. *Eur. J. Agron.* **2023**, *142*, 126643. [CrossRef]

31. Ditzler, L.; van Apeldoorn, D.F.; Pellegrini, F.; Antichi, D.; Bàrberi, P.; Walter, A.H. Rossing Current research on the ecosystem service potential of legume inclusive cropping systems in Europe. A review. *Agron. Sustain. Dev.* **2021**, *41*, 26. [CrossRef]
32. Tsegay, M.W.; Wallau, M.O.; Liu, C.; Dubeux, J.C.; Grabau, Z.J. Crop rotation for management of plant-parasitic nematodes in forage corn production. *Agron. J.* **2023**, *116*, 313–325. [CrossRef]
33. Shahzad, M.; Hussain, M.; Jabran, K.; Farooq, M.; Farooq, S.; Gašparovič, K.; Barboricova, M.; Aljuaid, B.S.; El-Shehawi, A.M.; Zuan, A.T.K. The Impact of different crop rotations by weed management strategies' interactions on weed infestation and productivity of wheat (*Triticum aestivum* L.). *Agronomy* **2021**, *11*, 2088. [CrossRef]
34. Watson, C.A.; Reckling, M.; Preissel, S.; Bachinger, J.; Bergkvist, G.; Kuhlman, T.; Lindström, K.; Nemecek, T.; Topp, C.F.E.; Vanhatalo, A.; et al. Chapter four—Grain legume production and use in European agricultural systems. *Adv. Agron.* **2017**, *144*, 235–303. [CrossRef]
35. Yimer, T.; Abera, G.; Beyene, S.; Rasche, F. Optimizing maize–bean cropping systems for sustainable intensification in southern Ethiopia. *Agron. J.* **2022**, *114*, 3283–3296. [CrossRef]
36. Koppelmäki, K.; Helenius, J.; Schulte, R.P.O. Nested circularity in food systems: A Nordic case study on connecting biomass, nutrient and energy flows from field scale to continent. *Resour. Conserv. Recycl.* **2021**, *164*, 105218. [CrossRef]
37. Semba, R.D.; Ramsing, R.; Rahman, N.; Kraemer, K.; Bloem, M.W. Legumes as a sustainable source of protein in human diets. *Glob. Food Sec.* **2021**, *28*, 100520. [CrossRef]
38. Pinto, E.; Ferreira, H.; Santos, C.S.; da Silva, M.T.; Styles, D.; Migliorini, P.; Ntatsi, G.; Karkanis, A.; Brémaud, M.-F.; de May, Y.; et al. Healthier and sustainable food systems: Integrating underutilised crops in a 'Theory of change approach'. In *Biodiversity, Functional Ecosystems and Sustainable Food Production*, 1st ed.; Galanakis, C.M., Ed.; Springer: Cham, Switzerland, 2023; pp. 275–323. [CrossRef]
39. Yfantopoulos, D.; Ntatsi, G.; Gruda, N.; Bilalis, D.; Savvas, D. Effects of the preceding crop on soil N availability, biological nitrogen fixation, and fresh pod yield of organically grown faba bean (*Vicia faba* L.). *Horticulturae* **2022**, *8*, 496. [CrossRef]
40. Ntatsi, G.; Karkanis, A.; Yfantopoulos, D.; Olle, M.; Travlos, I.; Thanopoulos, R.; Bilalis, D.; Bebeli, P.; Savvas, D. Impact of variety and farming practices on growth, yield, weed flora and symbiotic nitrogen fixation in faba bean cultivated for fresh seed production. *Acta Agric. Scand. B Soil Plant Sci.* **2018**, *68*, 619–630. [CrossRef]
41. Ntatsi, G.; Karkanis, A.; Yfantopoulos, D.; Pappa, V.; Konosonoka, I.H.; Travlos, I.; Bilalis, D.; Bebeli, P.; Savvas, D. Evaluation of the field performance, nitrogen fixation efficiency and competitive ability of pea landraces grown under organic and conventional farming systems. *Arch. Agron. Soil Sci.* **2019**, *65*, 294–307. [CrossRef]
42. Hara, T.; Sonoda, Y. The role of macronutrients for cabbage-head formation: I. Contribution to cabbage-head formation of nitrogen, phosphorus, or potassium supplied at different growth stages. *Soil Sci. Plant Nutr.* **1979**, *25*, 113–120. [CrossRef]
43. Atanasova, E.; Mitova, I.; Dimitrov, I.; Stancheva, I. Effect of different fertilizer sources on the quality of head cabbage. *J. Appl. Hortic.* **2007**, *9*, 74–76. [CrossRef]
44. Abera, G.; Gerkabo, H. Effects of green manure legumes and their termination time on yield of maize and soil chemical properties. *Arch. Agron. Soil Sci.* **2021**, *67*, 397–409. [CrossRef]
45. Sallaku, G.; Liko, J.; Rada, Z.; Balliu, A. The effects of legume crops (pea and faba Bean) on soil nutrients availability and yield parameters of subsequent cabbage crops under organic production conditions. *J. Environ. Sci. Eng.* **2016**, *5*, 619–625. [CrossRef]
46. Stein, S.; Zikeli, S.; Möller, K. Effect of leguminous green manure crops on white cabbage in organic vegetable production in southwestern Germany. *Acta Hortic.* **2022**, *1354*, 9–16. [CrossRef]
47. Inthichack, P.; Nishimura, Y.; Fukumoto, Y. Effect of potassium sources and rates on plant growth, mineral absorption, and the incidence of tip burn in cabbage, celery, and lettuce. *Hortic. Environ. Biotechnol.* **2012**, *53*, 135–142. [CrossRef]
48. Hartz, T.K.; Mitchell, J.P.; Giannini, C. Nitrogen and carbon mineralization dynamics of manures and composts. *HortScience* **2000**, *35*, 209–212. [CrossRef]
49. Kleinhenz, M.D.; Wszelaki, A. Yield and relationships among head traits in cabbage as influenced by planting date and cultivar. I. Fresh market. *HortScience* **2003**, *38*, 1349–1354. [CrossRef]
50. Paranhos, L.G.; Barrett, C.E.; Zotarelli, L.; Darnell, R.; Migliaccio, K.; Borisova, T. Planting date and in-row plant spacing effects on growth and yield of cabbage under plastic mulch. *Sci. Hortic.* **2016**, *202*, 49–56. [CrossRef]