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The Impact of Long-Term Fallowing on the Yield and Quality of Winter Rape and Winter and Spring Wheat

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Abstract: The proper fallowing of soil maintains or even improves its yield potential. The aim of this research was to compare five methods of soil protection with high production potential on the yield and quality of strategic plants. The tested methods consisted of five variants: bare fallow—BF; natural fallow—NF; fodder galega (*Galega orientalis* Lam.)—FG; a mixture of fodder galega (*Galega orientalis* Lam.) with smooth brome (*Bromus inermis*)—FG+SB; and smooth brome (*Bromus inermis*)—SB. The soil had been set aside for 9 years, after which time the fallows were terminated and the fields were cropped with winter oilseed rape, winter wheat, and spring wheat in three consecutive years. After the end of fallowing, the content of $N_{og.}$ and $C_{tot.}$, pH, and forms of available macro- and microelements in the soil were determined. The influence of each type of fallow on the yield of seeds/grain, straw, total protein, crude fat, and the content of macronutrients in the seeds/grain and straw of the grown crops was determined. Regarding the yields of the crops, the best solution was long-term soil protection via sowing fodder galega or a mixture of fodder galega and smooth brome. A field previously maintained as a fallow with these plants (singly or in combination) could produce over twice-as-high yields of wheat and oilseed rape as those harvested from a field established on bare fallow. The yields of the cereals and oilseed rape obtained in this study prove that food security and environmental protection issues can be reconciled. The methods for protecting farmland temporarily excluded from agricultural production presented in this paper correspond perfectly to the framework of the Green Deal for Europe. Arable land excluded from cultivation can be used to overcome new challenges facing modern agriculture.

Keywords: fallow land; marginal land; natural fallow; fertility soil; fallow management; crop yield

Citation: Sienkiewicz, S.; Żarczyński, P.J.; Wierzbowska, J.; Krzebietke, S.J. The Impact of Long-Term Fallowing on the Yield and Quality of Winter Rape and Winter and Spring Wheat. *Agriculture* **2024**, *14*, 567. https://doi.org/10.3390/agriculture14040567

Academic Editor: David Maxwell Freebairn

Received: 19 February 2024
Revised: 22 March 2024
Accepted: 1 April 2024
Published: 2 April 2024

1. Introduction

Soil is fundamental to agricultural production [1]. Due to progressing urbanisation, industrialisation, and natural erosion, soil resources in Poland, in Europe, and around the world are constantly diminishing [2–4]. Much valuable land has ceased to be used agriculturally and is subject to uncontrollable overgrowth of perennial plants, which gradually turn into permanent shrubbery and tree stands [5–8]. Thus, soil resources should be protected. The need for good land management and counteracting land degradation was raised at the United Nations forum (2015). The scope of the threats affecting agricultural land and the methods of counteracting them are defined as Goal No. 15: sustainable land management. The main tasks of this goal include combating desertification; regenerating degraded areas, including those affected by drought and floods; and creating a world that is neutral in terms of land degradation. The phenomena of agricultural land abandonment and the inappropriate management of fallow land have been identified as key threats to sound land management [3,9,10]. On the other hand, in an era of increasingly efficient agricultural production all over the world, yield surpluses are now obtainable under favourable conditions [11,12]. Thus, some farmland may be excluded from cultivation. The setting aside of fields occurred in Europe in the 1980s under the Common Agricultural Policy (CAP). The launch of this program for setting aside part of agricultural land in European Union countries was aimed at counteracting food overproduction [13,14]. Currently, it is not recommended to set fields in the EU aside for longer than 5 years. Land remaining fallow beyond this period may be reclassified as "permanent meadows and pastures", "forest or woodland land", or "other land". However, this depends on several factors, such as the percentage of permanent meadows in the total pool of these areas in a given country, the species of plant declared for subsidies, etc. [15]. After the outbreak of the war in Ukraine, the need to set aside land in Europe has been subject to numerous discussions and European farmers' protests, and no permanent agreements have been made yet.

However, there are situations (e.g., political and economic transformations) where agriculturally valuable lands are excluded from production. External circumstances such as those in the 1990s, for example, left over 2 million ha in Poland and 40 million ha in the former USSR uncultivated [3,16,17]. It is estimated that there is currently at least 16 million ha of uncultivated land in Europe, which is considered marginal land, fallows, or abandoned agricultural land [18]. Agricultural land that is properly set aside has a good chance of being integrated into the Green Deal for Europe. It is assumed that at least 10% of farmland should be dedicated to the restoration of landscapes with high biodiversity [19,20]. The land excluded from agricultural production needs to be protected from degradation [20,21]. To this end, many solutions have been developed that can protect soil and improve its fertility without giving rise to any major difficulties when returning the fallow land to production [22,23]. In order to ensure the best possible protection of set-aside soil, it is recommended to provide it with green cover consisting of at least several species of perennial plants, such as grasses or legumes. The following grasses are recommended: *Bromus inermis*, *Lolium perenne*, *Phleum* pratense, *Arundo donax*, and even *Miscanthus* sinensis or *Spartina* pectinata. The legumes suitable for long-term fallows are: *Galega orientalis*, *Medicago* sativa, *Trifolium repens*, and *Melilotus* suaveolens [24–27].

The best solution for environmental purposes seems to be maintaining mixtures of legumes and grasses on fallows. This composition reduces the accumulation of excessive nitrogen amounts in soil, enables the rectification of biodiversity issues, promotes better use of the productivity of grown species, and allows plants to adjust to the changeable conditions in the set-aside area [20,28,29]. Legumes are able to engage in symbiosis with nitrogen-fixing nodule bacteria and can therefore thrive without nitrogen fertilization. Leguminous plants grown to protect fallows are able to sequestrate carbon effectively and retain nitrogen, phosphorus, and potassium in agricirculation [29–31].

Fodder galega produces considerable amounts of valuable biomass and has been widely acknowledged as a useful plant for the protection of set-aside farmland. It is tolerant to very-low temperatures and, from the perspective of maintaining a fallow for many years, copes well with weeds. Galega's well-developed root system provides fodder galega with good access to water, even when rainfall is scarce, and enables the uptake of nutrients from the soil's natural pool, not always available for other plants. Sowing fodder galega alone or mixed with smooth brome in order to protect set-aside fields has a positive effect on the soil abundance of C-org and N-total as well as the available forms of macro- and micronutrients [29,32–36]. Growing galega with grasses can decrease the emission of NO_x and promotes sustainable agriculture and the sourcing of good-quality strategic raw materials [32,37,38].

Smooth brome is a tall grass with very modest requirements. This species is even considered to be an invasive one. Its significant resistance to periodic droughts and high adaptability ensure consistent yields. These characteristics allow smooth brome to produce compact swards in different soil conditions for at least several years. Moreover, smooth brome is able to accumulate nutrients in root systems and rhizomes, which makes it more competitive in a sward than other species, especially in the spring [39–41].

A well-planned and managed fallow results in improved physical, chemical, and biological properties of soil, and some researchers even suggest that soil undergoes some form of regeneration during this management period [42]. Once a properly established fallow is terminated, the corresponding soil is free from pathogens and, simultaneously, rich in nutrients [43–45]. Many factors influence the final yield of rape seeds [46,47]. The discontinuation of the cultivation of cereals and oilseed rape lasting for a few years is very beneficial and may result in an increase in yield by over 25% when winter oilseed rape is cultivated afterwards [48,49].

There are few studies concerning the effects of long-term fallowing (soil regeneration) on the yields of plants. Likewise, there are few suggested methods for the effective protection of set-aside land that can be applied on an industrial scale. The reports found in the literature typically deal with 1–3-year intervals in crop cultivation and mostly refer to the evaluation of the impact of fallowing on the yields of crops grown in the first year after terminating the fallowing period. This paper is the last link in a series of studies associated with the chemical properties of soils subjected to different fallowing plans after they return to cultivation. The results demonstrated that the soil's yield potential improved after a few years of fallowing owing to increased soil fertility. In the study discussed herein, it was assumed that leguminous plants or their mixtures with grasses would be good pre-crops on fields set aside for many years and should therefore be evaluated on the basis of a three-year cultivation of species with high nutritional requirements and high economic importance on former fallows.

Our research hypothesis assumes that soil fallowing with the use of fodder galega and its mixture with smooth brome has a positive impact on the yields of commercial plants, namely, winter rapeseed, winter wheat, and spring wheat, and modifies their chemical compositions.

The aim of this research was to determine the effect of different long-term fallowing methods (the use of bare fallow, natural fallow, fodder galega, fodder galega with smooth brome, and smooth brome) on the yields of winter rape, winter wheat, and spring wheat as well as the chemical compositions of the plants after the direct liquidation of set-aside land.

2. Materials and Methods

The field experiment, situated in Knopin (53°57′29″ N 20°24′21″ E Poland), was composed of two stages. The first stage consisted of maintaining 9-year-long fallows. In spring 1996, a field experiment was started in a randomized block design. It was established on a Haplic Cambisol originating from boulder clay (WRB 2006). The following fallows were created: 1—bare fallow (BF), 2—natural fallow (NF), 3—fodder galega (FG), 4—fodder galega with smooth brome (FG+BG), and 5—smooth brome (BG). Soil was kept as bare fallow by performing mechanical weeding a few times a year. No agrotechnical treatments were carried out on the other types of fallows, and the whole biomass was left on field.

In 2004, the fallows were terminated, and commodity crops were grown. After completion of fallowing, soil samples were collected from each fallow in the 0–25 cm layer for analysis. In order to completely eliminate vegetation, glyphosate was used (1.44 kg/ha). Then, a flail mower (BBK 180M Pronar, Narew, Poland) was used to mow biomass residues on grass-covered fields, and a disc harrow (CUT/XL 4.0, Unia Grudziądz, Poland) was run twice through the fields. In the subsequent step, all fields were tilled (Unia Kret 3B, Unia Grudziądz, Poland) to 50 cm; two weeks later, a disc harrow was used twice, and the fields were ploughed to a depth of 25 cm (Kverneland LB100, Klepp, Norway) and harrowed. Once the soil had been prepared as described above, mineral fertilizers were spread. The crops were fertilized in line with the fertilization plan shown in Table 1. Winter oilseed rape cv. Bazyl was sown using a cultivation-sowing unit (Kverneland KLH + DA with disc coulters, Klepp, Norway). In the two subsequent years, winter wheat cv. Mewa and spring wheat cv. Zadra were sown. During the three-year study, full ploughing cultivation and chemical protection were carried out on all fields. The decision to carry out chemical treatments was made for each crop separately, according to the thresholds of harmfulness and the current condition of the plants' development. The range of chemical protection methods is presented in Table 2. After the crops were harvested, the straw was weighed and removed from the experimental fields.

Table 1. Fertilization of the crops.

Plant	Type of Fertilizer	Dose kg/ha	Application Form	Stage of Development
Winter rape	Ammonium nitrate	30 N	to soil	before sowing
	Single superphosphate	40 P	to soil	before sowing
	Potassium salt	120 K	to soil	before sowing
	Ammonium nitrate	80 N	top-dressing	BBCH 30
	Ammonium nitrate/Ammonium sulfate	80 N+40 S	top-dressing	BBCH 35
Winter wheat	Ammonium nitrate	30 N	to soil	before sowing
	Single superphosphate	40 P	to soil	before sowing
	Potassium salt	120 K	to soil	before sowing
	Ammonium nitrate	60 N	top-dressing	BBCH 22
	Ammonium nitrate	60 N	top-dressing	BBCH 32
	Ammonium nitrate	40 N	top-dressing	BBCH 72
Spring wheat	Ammonium nitrate	60 N	to soil	before sowing
	Single superphosphate	40 P	to soil	before sowing
	Potassium salt	120 K	to soil	before sowing
	Ammonium nitrate	60 N	top-dressing	BBCH 32

Table 2. Chemical protection of the crops grown on terminated fallows.

Plant	Chemical Agent	Type of Active Substance	Dose g/ha	Stage of Development
Winter rape	Command 480 EC	Clomazon	120	BBCH 00
	Butisan 500 SC	Metazachlor	750	BBCH 00
	Agil 100 EC	Propachizafop	100	BBCH 25
	Caramba 60 SL	Metconazole	42	BBCH 25
	Sparta 250 EW	Tebuconazole	175	BBCH 43
	Nurelle D 550 EC	Chlorpyrifos	300	BBCH 55
		Cypermethrin	30	
	Alert 375 EC	Flusilazole	125	BBCH 67
		Carbendazim	250	
	Mospilan 20 SP	Acetamiprid	30	BBCH 67
Winter wheat	Granstar 75 WG	Tribenuron methyl	18.75	BBCH 22
	Tilt plus 400 EC	Propiconazole	125	BBCH 31
		Fenpropidin	275	
	Soprano 125 EC	Epoxiconazole	125	BBCH 51
	Sparta 250 EC	Tebuconazole	125	BBCH 51
Spring wheat	Apyros 75 WG	Sulfosulfuron	19.5	BBCH 22
	Artea 330 EC	Propiconazole	125	BBCH 51
		Cyproconazole	40	

The value of the harvest index (HI) was calculated using the following formula:

$$HI = Ya/(Ya + Yb)$$

The variables used in the formula above are explained below:

HI—harvest index;

Ya—seeds/grain yield [t/ha];

Yb—straw yield [t/ha].

The cumulated yield from the three years of the experiment was expressed in cereal units, which were calculated with the help of yield conversion factors given in the Annex to the Regulation of the Minister of the Environment of 2019 [50].

2.1. Chemical Analyses

Samples of seeds/grain and straw were collected at harvest. In order to determine the content of macronutrients, the plant material was dried at 60 °C (Premed KBC G-100/250, Warszawa, Poland) and ground (Retch SM 100, Retsch GmbH, Haan, Germany), after which it was ashed in concentrated H_2SO_4 with added H_2O_2 as an oxidizer (Büchi SpeedDigester K-439, BÜCHI Labortechnik AG, Flawil, Switzerland). The N-total content was determined via the Kjeldahl method (Büchi KjelFlex K 360 apparatus, BÜCHI Labortechnik AG, Flawil, Switzerland). The protein content in seeds/grain was calculated with a coefficient of 6.25 (ISO 5983-1:2005) [51]. The content of P was measured colorimetrically using the vanadium-molybdate method (Shimadzu UV 1201V, Shimadzu Corporation, Kyoto, Japan), while the content of K, Ca, and Na was determined using atomic emission spectrometry (AES—a flame photometer produced by BWB Technologies Ltd., Newbury, UK), and the content of Mg was determined using atomic absorption spectrometry (AAS—Schimadzu AA-6800, Shimadzu Corporation, Kyoto, Japan). The determinations of macronutrients in the plant material were verified using the certified material VTL-2. The content of crude fat was determined using the Soxhlet method (Foss Soxtec System 2043 Extraction Unit, Hilleroed, Denmark).

Soil samples for chemical analyses were collected from a depth of 0–25 cm when the fallows were terminated. pH was determined in 1 mol/dm^3 of KCl via the potentiometric method using an electrode with temperature compensation within a temperature range of 20 °C. Total organic carbon (C-org) was measured with a Vario Max Cube CN Elementar analyzer, Langenselbold, Germany). The N-total content was determined via the Kjeldahl method (KjelFlex K-360 device, BÜCHI Labortechnik AG, Flawil, Switzerland). The available forms of P and K were extracted from soil with buffered calcium lactate at pH = 3.55 (via the Egner–Riehm method). Next, P content was determined using colorimetry via the molybdate method, using tin(II) chloride as a reducer, while K content was determined via the AES method using a flame photometer produced by BWB Technologies. Available Mg was extracted from soil with 0.0125 mol/dm^3 of $CaCl_2$ solution (Schachtschabel method), while micronutrients (Zn, Cu, and Mn) were extracted in 1 mol/dm^3 of HCl, and their proportions were determined using the AAS method (AAS—Schimadzu AA-6800). Selected soil properties from the research objects before fallows were established are presented in Table 3.

Table 3. Soil characteristics after termination of fallows (2004).

Objects	$C_{org.}$	$N_{tot.}$	pH	Available Forms					
			mol/dm^3 KCl	P	K	Mg	Cu	Zn	Mn
	g/kg	g/kg		mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg
BF	9.47	0.92	5.25	75.15	191.50	66.93	3.81	20.19	127.64
NF	11.53	1.39	5.15	78.80	207.50	74.87	3.62	22.56	98.39
FG	14.47	1.43	5.30	116.50	208.50	85.50	3.30	25.21	116.27
FG+SB	12.53	1.39	5.40	78.83	183.50	83.85	2.68	24.43	124.01
SB	11.76	1.33	5.00	67.75	182.50	64.25	2.49	22.07	113.22

BF—bare fallow; NF—natural fallow; FG—fodder galega (*Galega orientalis* Lam.); FG+SB—a mixture of fodder galega (*Galega orientalis* Lam.) with smooth brome (*Bromus inermis*); SB—smooth brome (*Bromus inermis*).

2.2. Statistical Methods

Crop yields and results of chemical analyses were processed statistically the Statistica 13.3 software package. Before performing statistical analyses, assumptions about the normal distribution of variables within each group were checked. The impact of the fallowing method on plants' yields and their derivatives as well as the chemical compositions of plants were assessed using one-way analysis of variance (ANOVA). In the next stage of statistical analyses, post hoc comparisons were madeusing the Tukey test (HSD), with $p < 0.05$.

In order to isolate similarities between the methods of securing set-aside land, cluster analysis was used. Analysis of variance was used to estimate the distance between clusters in order to minimize the sum of the squared deviations within the clusters. When forming clusters, we used the Euclidean distance, which is given by the following formula:

$$d(x,y) = \sqrt{\sum_{i=1}^{n} (x_i - y_i)^2}$$

where x (yields) = $(x_1, x_2, \ldots, x_n)$ i y (distance) = $(y_1, y_2, \ldots, y_n)$.

Analyses were performed for standardized variables. The obtained results were subjected to comparative and descriptive analysis. The Statistica 13.3 software package was used for calculations.

3. Results and Discussion

3.1. Crop Yields

1. Winter rape

In this study, the way set-aside soil was protected significantly modified the yields of seeds and straw of winter oilseed rape and the grain and straw of winter wheat and spring wheat (Table 4). Most crops tend to respond quite demonstrably to the crop grown in the same field before [52,53]. Our own research confirmed this phenomenon.

Table 4. Yields of the crops in the years 2005–2007.

Object	Winter Rape (2005)		HI	Winter Wheat (2006)		HI	Spring Wheat (2007)		HI
	Seeds	Straw		Grain	Straw		Grain	Straw	
	t/ha	t/ha		t/ha	t/ha		t/ha	t/ha	
BF	1.86 ^{a}	4.05 ^{a}	0.32 ^{b}	3.96 ^{a}	4.78 ^{a}	0.45 ^{a}	3.37 ^{a}	4.26 ^{a}	0.44 ^{a}
NF	2.42 ^{b}	6.48 ^{bc}	0.27 ^{a}	5.41 ^{b}	6.79 ^{c}	0.44 ^{a}	4.18 ^{b}	5.12 ^{b}	0.45 ^{a}
FG	4.38 ^{c}	7.41 ^{cd}	0.37 ^{c}	6.53 ^{c}	7.61 ^{d}	0.46 ^{ab}	6.73 ^{c}	8.13 ^{c}	0.46 ^{a}
FG+SB	4.24 ^{c}	7.66 ^{d}	0.36 ^{c}	6.68 ^{c}	7.20 ^{cd}	0.48 ^{b}	6.99 ^{c}	8.19 ^{c}	0.45 ^{a}
SB	2.31 ^{b}	5.47 ^{b}	0.30 ^{ab}	5.58 ^{b}	6.04 ^{b}	0.48 ^{b}	4.46 ^{b}	5.23 ^{b}	0.46 ^{a}

$^{a\text{–}d}$—significant differences at $p \leq 0.05$ between objects of experiment; average annual yield. BF—bare fallow; NF—natural fallow; FG—fodder galega (*Galega orientalis* Lam.); FG+SB—a mixture of fodder galega (*Galega orientalis* Lam.) with smooth brome (*Bromus inermis*); SB—smooth brome (*Bromus inermis*); HI—harvest index.

The yield of oilseed rape seeds ranged from 1.86 to 4.38 t/ha. The most positive effect on this crop's yield was achieved for the objects where fodder galega or fodder galega with smooth brome had been grown before the fields were returned to agricultural production. Slightly lower yields ranging from 1.55 to 3.53 t/ha with similar nitrogen fertilization levels were achieved by Jankowski and Nogalska [54]. Fullen et al. [24] point to the necessity of keeping some plant cover on a fallow because it contributes to the improvement of soil's physicochemical properties when the fallow is terminated. In this context, Żarczyński et al. [20] claim that the selection of plants that will be grown on set-aside ground is an extremely important issue. According to these authors and Fordoński et al. [55], growing leguminous plants on set-aside fields is highly recommended. Faligowska et al. [56] underline that using legumes as a preceding crop leads to an increase in yields of cereals and oilseed rape. A significantly lower yield of seeds was harvested from fields established on fallows covered with smooth brome or with natural plant communities. When turned into a field and cropped with oilseed rape, a natural fallow with natural plant cover enabled a rape seed yield of 2.42 t/ha. Based on a study conducted in another part of the world, Tian et al. [57] identified the potential yields of oilseed rape grown on fields established on natural fallows in China at 1.95 t/ha.

The yields obtained from the bare fallow turned into a field—compared with the other objects where plant cover had been kept during the set-aside period—indicate a drastic decrease in the fertility of soil kept as bare fallow (Table 4). The nine-year-long absence of plant cover combined with the frequent use of passive soil tillage tools led to a situation where the mass of seeds harvested from an area unit was less than half of the amount collected from the research objects established on the fallows with plant cover composed of fodder galega or fodder galega mixed with smooth brome. Previous research by the authors of this study [45] showed that fodder galega and its mixture with smooth brome contribute significantly greater amounts of mineral nitrogen to soil compared to black fallow, natural fallow, or a smooth brome monoculture. This may be the main reason for the increase in rapeseed yield. According to many authors [54,58], rapeseed reacts with a significant increase in yield in soil richer in nitrogen.

Biomass left on set-aside land and the way it is incorporated into soil (ploughing or mulching) have a large impact on the yield of crops cultivated on former fallows. The mulching of fallows and avoiding the placement of biomass too deep into the soil increase their temperature and moisture. The effect of plant residues after a fallow is turned into a field is beneficial because it improves water retention in the soil down to at least 40 cm in depth, which results in higher yields of cultivated crops [59]. Kalembasa et al. [60] found that crops grown in the second and third year continued to take up about 30% of N from harvest residues of previously grown legumes. On the other hand, due to large amounts of produced biomass in the form of aerial organs and developed root systems, legumes create conditions that promote an increase in the content of C_{org} in soil. Soil tillage treatments that are needed to turn a fallow into a productive field accelerate the rate of organic matter mineralization, which enables plants to use accumulated pools of nutrients. According to Radočaj et al. [61], the pre-cropping value of a stand depends largely on the C/N ratio in harvest residues, which determines the course of mineralization and immobilization processes. A similar positive effect of mineralizing organic matter could have occurred for the yield of winter rapeseed in our own research.

The way the set-aside soil was maintained had a lesser impact on the yield of oilseed rape straw compared to that on its seeds (Table 4). Most straw was harvested from the fields that had been kept as fallows covered with fodder galega or fodder galega mixed smooth brome (7.41 and 7.66 t/ha). The lowest yield of straw, the same as the yield of seeds, was obtained from the research object that had been maintained for 9 years as bare fallow. As it is crucial to take care of organic matter resources due to the insufficient amounts of fertilizers of animal origin and high saturation with cereals on commodity farms, straw left after harvest, especially winter oilseed rape straw, is becoming more important. There are provisions under the Green Deal for Europe enforcing the need to manage nutrients in a more responsible manner. The new agricultural policy suggests reducing the doses of nutrients included in fertilizers by 20%, limiting losses of nutrients by 50%, and increasing the content of organic carbon in soil [19]. Leaving straw in a field and mixing it with the soil currently fits into one of the eco-schemes of the current agricultural policy. According to Puppe et al. [62], the recycling of straw is already providing numerous environmental benefits, and, in the future, it will play a key role in sustainable agriculture, helping to reduce the amounts of fertilizers applied.

The harvest index (HI) displays the ratio of the main yield to the aerial biomass produced by a crop. The greatest differentiation in this parameter was noted in the first year after the transformation of the fallows into cultivated fields (Table 4). When the fallow with natural plant cover was ploughed, the harvest index of winter oilseed rape grown there was the lowest (HI = 0.27), possibly implying that the development of oilseed rape on this field did not proceed properly, especially in the generative stage. The highest share of main yield in the aerial biomass of winter oilseed rape was recorded on fields established on fallows covered with fodder galega or a mixture of fodder galega and smooth brome.

2. Winter wheat

The highest yields of grain from winter wheat were harvested from the fields that were established on fallows covered with fodder galega (6.53 t/ha) or with fodder galega mixed with smooth brome (6.68 t/ha) (Table 4). Less grain was collected from the fields that used to be maintained as fallows and had subsequently experienced an overgrowth of smooth brome or a natural plant community. Significantly, the lowest grain yield was obtained from the field established on a bare fallow (3.96 t/ha). Pszczółkowska et al. [63] noted a considerable increase in the yield and a simultaneous increase in the nitrogen content of grains of wheat grown after the planting of faba bean. A similar outcome was achieved when a field was set aside for one year and soybean was used as a green fertilizer [64]. In this way, the fertilization of wheat with nitrogen can be reduced by as much as 30% without compromising the wheat yield. The above-mentioned factors, as well as reports by Kalembasa et al. [60], may explain the potential reason for the better yield of winter wheat in fields containing fodder galega. The authors' own research based on the same experiment also showed a higher content of organic carbon, total and mineral nitrogen, and macro- and micro-nutrients available in objects containing fodder galega [29,33,35,45]. A higher level of the above-mentioned soil parameters certainly had a positive effect on the wheat yields.

The yield of winter wheat straw depended on the way the set-aside soil had been maintained (Table 4). As with grain yields, the highest straw yield was obtained from the fields that had been established on fallows covered with fodder galega or with a mixture of fodder galega and smooth brome (7.61 and 7.20 t/ha, respectively). The least amount of straw was harvested from the field that used to be bare fallow (4.78 t/ha). The yield of straw is economically less important than the yield of seeds or grains, but straw can serve as a valuable biomass for enriching soil with organic matter and nutrients, so it should be left on a field and ploughed into the soil [65]. On the other hand, it is worth noting that the dynamically developing pellet market is processing increasing quantities of straw [66,67].

The impact of the previous fallow management solutions on the harvest index of winter wheat was distinctly weaker than the impact on the HI of winter oilseed rape. Compared with winter wheat cultivated on a field previously used as a bare fallow or natural fallow, a significantly higher ratio of grain to total aerial biomass was determined for wheat grown on fields established on fallows covered with fodder galega, smooth brome, or a mixture of both (HI = 0.46–0.48).

3. Spring wheat

Spring wheat was grown in the third year after the discontinuation of fallows, and yields of this crop were also evidently differentiated by how the set-aside soil had been maintained (Table 4). The highest spring wheat yield, the same as yields from the other two crops, was obtained from the fields that were started on fallows overgrown with fodder galega or fodder galega mixed with smooth brome (6.67 and 6.69 t/ha, respectively). Skuodiene and Nekrosiene [68] draw attention to the slow rate of decomposition of residues from leguminous plants and emphasize that the strongest effect on yield appears in the second year after the termination of perennial plantations. This often translates into higher yields of crops grown in the second rather than first year after long-term planting of legume plants is stopped. Bloger et al. [69] even suggest that there is a three-year-long positive impact of perennial plantations of small-seed leguminous plants on yields of the subsequent crops. This results from the different thicknesses of the root systems of legumes and consequently the different times needed to decompose the roots. The differences in spring wheat yields in our own research can be explained similarly. It should be remembered that in this experiment, all fallow biomass remained in the field. It was a considerable source of nutrients [25].

Significantly less grain was yielded by wheat grown on a field established on natural fallow or on fallow covered with smooth brome. The least amount of grain was collected from a field that, prior to returning to agricultural production, had been a bare fallow, and this yield was less than half of the yield obtained from a field that had been covered with fodder galega during the fallowing period.

Keeping set-aside soil as bare fallow prevents the spread of weeds and ensures a certain readiness of the soil to be sown. According to Ennaïfar et al. [70], maintaining soil as bare fallow may have a positive influence on the yields of the crops grown on such soil after the fallow has been terminated. This method of fallowing ground may enable considerable eradication of diseases on the fallow, which, in turn, results in higher yields when the set-aside field is returned to agricultural production. However, this study did not confirm this opinion. Sienkiewicz et al. [33] concluded that maintaining bare fallow as such for several years led to a considerable decline in its fertility.

The way the set-aside soil had been maintained also had a significant influence on the yields of straw of spring wheat (4.26–8.19 t/ha; Table 4), and the relationships observed were similar to the ones noted for grain yields. No significant differences were determined in the HI for spring wheat straw depending on the way the set-aside soil had been kept (Table 4).

3.1.1. Crop Yields Expressed in Cereal Units

The total yields of all the crops grown for three years on all the experimental fields are expressed in cereal units (CU)/ha [45] (Figure 1).

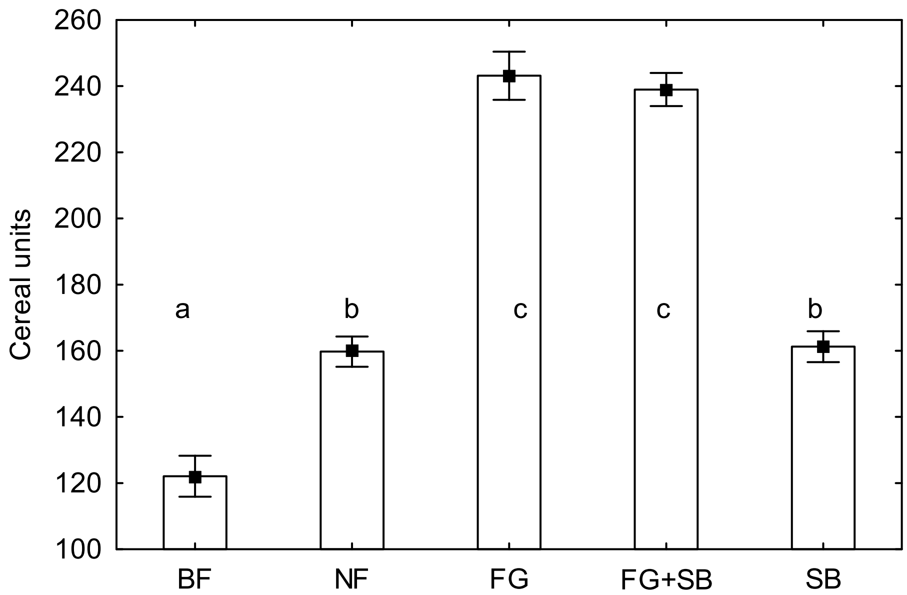

Figure 1. Crop yield in cereal units (total from 3 years of trials ± standard deviation). a–c—significant differences at $p \leq 0.05$ between objects of experiment.

The yields of the tested species on fields created from bare fallow or fallow swarded with smooth brome were within 160 CU. The bare fallow converted to a field produced a yield that was about 25% lower. In turn, the yields from the fields established on fallows covered for 9 years with fodder galega or its mixture with smooth brome were about 40% higher than those obtained from fields started on fallows with natural plants or sown with smooth brome. When the fallows covered with natural plants and with smooth brome were turned into production fields, the yields of the three tested plant species were at approximately the same level. This proves that keeping fallow covered with grass creates a similar yield-stimulating effect to when fallow is left to become overgrown through the natural succession of plants.

3.1.2. Yields of Crude Fat and Total Protein

1 Winter rape

Winter oilseed rape grown on fields established on the fallows swarded with fodder galega or its mixture with smooth brome produced the highest yields of crude fat: 1939 and 1886 kg/ha, respectively (Figure 2).

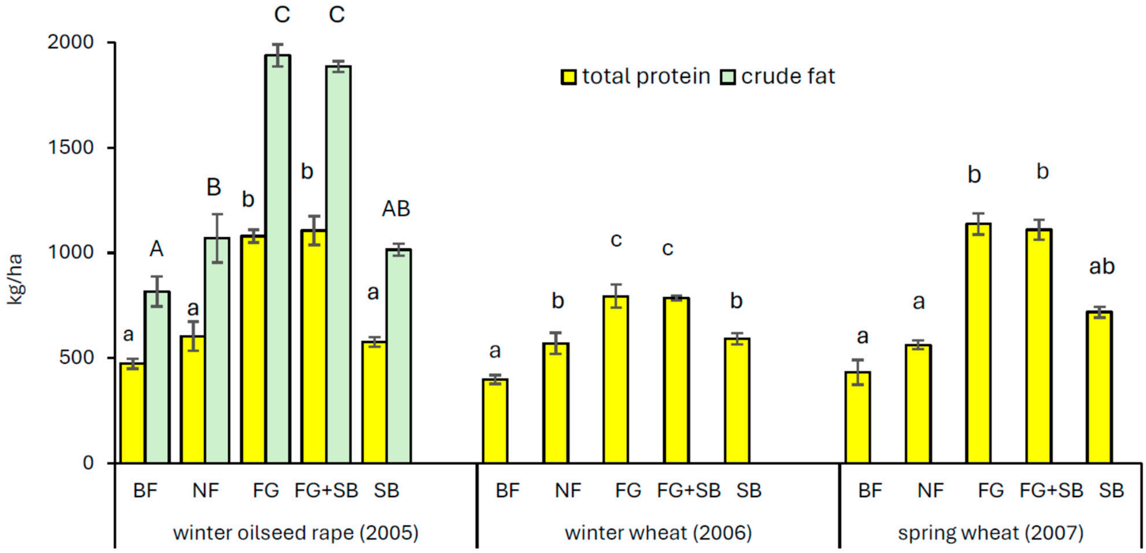

Figure 2. Yields of total protein and crude fat in the years 2005–2007. a–c—significant differences of total protein at $p \leq 0.05$ between objects of experiment. A–C—significant differences of crude fat at $p \leq 0.05$ between objects of experiment.

Leaving uncultivated soil exposed to the natural succession of plants (NF) or as fallow sown with smooth brome (SB) resulted in a decrease in crude fat yield by nearly 50%. Significantly, the lowest yield of crude fat was obtained from the research object established on the bare fallow for which farming had resumed. According to Jankowski et al. [71], the content of antinutrient substances in the seeds of oilseed plants cultivated nowadays is low. Owing to modern technologies that enable protein refinement, extraction meal can be used for feeding a growing number of farm animals. As a result, the content of protein and its yield per 1 ha of oilseed rape plantation are gaining importance.

As with the yield of crude fat, the highest yield of total protein in winter oilseed rape seeds was obtained from the fields established on fallows swarded with fodder galega or its mixture with smooth brome: 1080 and 1106 kg/ha, respectively (Figure 3). In turn, the lowest total protein yield (473 kg/ha) was obtained from the research object wherein oilseed rape was grown after the termination of the bare fallow.

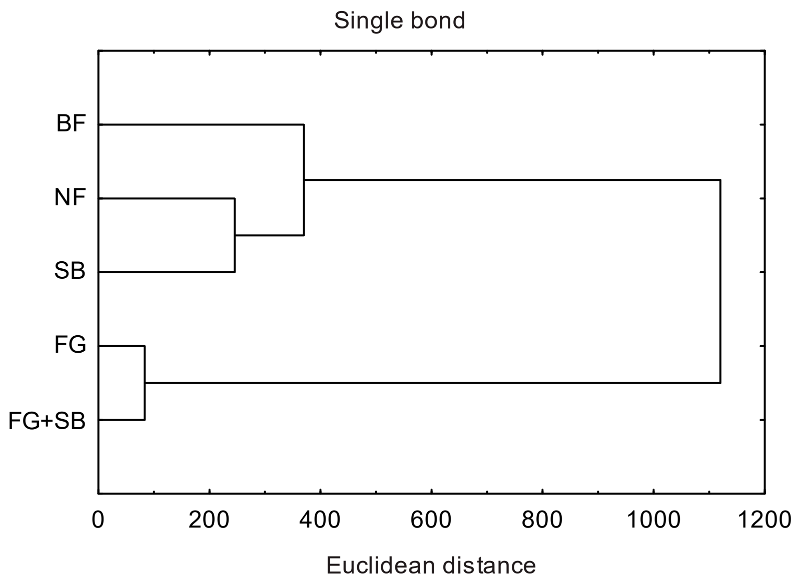

Figure 3. Dendrogram of the effect of long-term fallows (9-years) on yields and quality of yields produced by crops of winter rapeseed, winter wheat, and spring wheat in the years 2005–2007.

2 Winter and spring wheat

The yields of total protein accumulated in winter wheat and spring wheat demonstrated similar relationships to the yields of fat and protein harvested with winter oilseed rapeseed. The content of protein in the grains of cereals, especially wheat, is of key importance in grain processing. Winter wheat contains less protein than spring wheat [72]. In this study, the yields of spring wheat protein were also higher than those of winter wheat. The way the set-aside soil had been maintained affected the yield of protein produced by both winter and spring wheat. The highest protein content was determined in the grain harvested from the research objects that had experienced an overgrowth pf fodder galega or its mixture with smooth brome. Buraczyńska and Ceglarek [73] achieved an increase of 38% in the protein yield in grains of winter wheat grown after peas were planted in comparison to the yield of wheat following cereal growth. Very similar effects were obtained in this study: when the fallow covered with fodder galega was turned into a field, the protein content in the grains of winter wheat increased by 34% in comparison to that in the field created from the fallow covered with smooth brome and by over 39% relative to the field established on the natural fallow.

3.2. Mineral Composition of Plants

1 Winter oilseed rape

The way the set-aside soil had been maintained had no effect on the concentration of N in winter oilseed rape seeds, and the content of this element varied within a small range of 39.90–40.73 g/kg DM (Table 5).

Table 5. Content of macronutrients in seeds and straw of winter rape 1 year after the end of fallowing.

Objects	Seeds						Straw					
	N	P	K	Ca	Mg	Na	N	P	K	Ca	Mg	Na
	g/kg DM											
BF	39.90 ^{a}	9.32 ^{b}	8.12 ^{a}	5.92 ^{a}	3.06 ^{a}	0.09 ^{a}	6.95 ^{b}	1.57 ^{b}	16.41 ^{a}	11.75 ^{b}	1.05 ^{b}	0.12 ^{a}
NF	39.92 ^{a}	9.06 ^{a}	8.21 ^{a}	6.17 ^{b}	3.09 ^{a}	0.10 ^{a}	6.57 ^{b}	1.40 ^{a}	17.59 ^{b}	10.30 ^{a}	0.88 ^{a}	0.12 ^{a}
FG	40.73 ^{a}	9.82 ^{c}	8.41 ^{b}	6.30 ^{b}	3.16 ^{a}	0.11 ^{a}	7.52 ^{c}	1.89 ^{d}	21.31 ^{d}	13.32 ^{c}	1.02 ^{b}	0.14 ^{b}
FG+SB	40.71 ^{a}	9.85 ^{c}	8.72 ^{b}	6.01 ^{ab}	3.11 ^{a}	0.12 ^{a}	7.64 ^{c}	1.78 ^{c}	20.11 ^{c}	13.22 ^{c}	1.03 ^{b}	0.14 ^{b}
SB	40.50 ^{a}	9.71 ^{bc}	9.11 ^{c}	6.04 ^{ab}	3.11 ^{a}	0.12 ^{a}	5.76 ^{a}	1.60 ^{b}	17.28 ^{ab}	11.33 ^{b}	0.93 ^{a}	0.12 ^{a}

$^{a–d}$—significant differences at $p \leq 0.05$ between objects of experiment; BF—bare fallow; NF—natural fallow; FG—fodder galega (*Galega orientalis* Lam.); FG+SB—a mixture of fodder galega (*Galega orientalis* Lam.) with smooth brome (*Bromus inermis*); SB—smooth brome (*Bromus inermis*).

Most P accumulated in the seeds of winter rape grown on fields established on former fallows covered with fodder galega or with its mixture with smooth brome (9.82 and 9.85 g/kg DM, respectively). Significantly, the highest K content was found in seeds of rape grown after smooth brome had been planted (9.11 g/kg DM); in contrast, the least K was contained in seeds of rape cultivated on fields established on a bare fallow and natural fallow (8.12 and 8.21 g/kg DM). The way soil was kept as a fallow did not have a significant effect on the content of Mg and Na in winter oilseed rape seeds. Stępień et al. [74] maintain that the effect of a preceding crop on the mineral composition of oilseed rape seeds is small.

The fallow methods influenced the concentrations of macronutrients in winter oilseed rape straw (Table 5). Significantly, most N was contained in the straw of winter rape grown on fields established on fallows covered with fodder galega or its mixture with smooth brome (7.52 and 7.64 g/kg DM, respectively). The least amount of N was determined in the straw of rape cultivated after the termination of the fallow swarded with smooth brome (5.76 g/kg DM). The P content of winter oilseed rape straw ranged from 1.40 to 1.89 g/kg DM. The least amount of this element was determined to be in straw from the field created from the natural fallow, while its highest content was detected in straw harvested from a field established on the fallow covered with fodder galega.

2 Winter wheat

The analysis of the mineral compositions of winter wheat grain proved that the impact of the different fallow methods was visible in the second year after the discontinuation of the fallows in terms of the mineral content of wheat grain (Table 6).

Table 6. Content of macronutrients in grain and straw of winter wheat 2 years after the end of fallowing.

Objects	Grain						Straw					
	N	**P**	**K**	**Ca**	**Mg**	**Na**	**N**	**P**	**K**	**Ca**	**Mg**	**Na**
	g/kg DM											
BF	16.10 ^{a}	5.57 ^{b}	4.80 ^{b}	0.37 ^{a}	0.76 ^{a}	0.21 ^{a}	4.13 ^{a}	1.86 ^{b}	4.38 ^{a}	1.77 ^{a}	0.39 ^{a}	0.09 ^{a}
NF	16.87 ^{b}	5.60 ^{b}	4.62 ^{a}	0.42 ^{b}	0.82 ^{b}	0.21 ^{a}	4.32 ^{ab}	2.02 ^{c}	5.93 ^{b}	1.78 ^{a}	0.50 ^{b}	0.13 ^{a}
FG	19.44 ^{c}	5.88 ^{d}	4.82 ^{b}	0.41 ^{b}	0.89 ^{c}	0.21 ^{a}	5.15 ^{d}	2.19 ^{d}	7.97 ^{d}	2.16 ^{b}	0.55 ^{c}	0.12 ^{a}
FG+SB	18.83 ^{c}	5.75 ^{c}	4.99 ^{c}	0.42 ^{b}	0.92 ^{c}	0.21 ^{a}	4.94 ^{cd}	1.95 ^{bc}	7.11 ^{c}	2.02 ^{b}	0.59 ^{c}	0.13 ^{a}
SB	16.98 ^{b}	5.33 ^{a}	4.74 ^{ab}	0.42 ^{b}	0.78 ^{ab}	0.20 ^{a}	4.68 ^{bc}	1.67 ^{a}	7.08 ^{c}	1.84 ^{a}	0.40 ^{a}	0.09 ^{a}

$^{a-d}$—significant differences at $p \leq 0.05$ between objects of experiment; BF—bare fallow; NF—natural fallow; FG—fodder galega (*Galega orientalis* Lam.); FG+SB—a mixture of fodder galega (*Galega orientalis* Lam.) with smooth brome (*Bromus inermis*); SB—smooth brome (*Bromus inermis*).

The highest differentiation was observed relative to the N content of winter wheat grain. Most of the content of this element was found in the grains of winter wheat grown in the second year after the termination of the fallows swarded with fodder galega or fodder galega mixed with smooth brome (19.44 and 18.83 g/kg DM, respectively). A similar response of winter wheat to the preceding crop being a leguminous plant has been reported by Pszczółkowska et al. [63]. Less N was found in the grains harvested from the fields established on the natural fallow and the fallow with a monoculture of smooth brome (16.87 and 16.98 g/kg DM, respectively). Significantly, the lowest P content was found in the grains of winter wheat grown on the field established on the fallow covered with smooth brome alone (5.33 g/kg DM), while the highest concentration of this element accumulated in the grains harvested from the field established on the fallow covered with fodder galega (5.88 g/kg DM). The grains of winter wheat cultivated after the termination of the bare fallow contained significantly less Ca and Mg than the grains collected from the other research objects. Slightly different results were obtained by Wanic et al. [75], who concluded that the preceding crop, pea or oilseed rape, did not alter the content of P, K, Mg, and Ca in wheat grain. The content of macronutrients in winter wheat straw also depended on the way the set-aside ground was maintained (Table 6). The highest N content was found in the straw harvested from the research objects that had been kept as fallow soil covered with fodder galega or fodder galega mixed with smooth brome (5.15 and 4.94 g/kg DM, respectively). The N-poorest straw was obtained from the fields established on the terminated bare fallow or natural fallow. The P content in winter wheat straw ranged from 1.67 g/kg DM (a monoculture of smooth brome) to 2.19 g/kg DM (a monoculture of fodder galega). The concentrations of K in winter wheat straw varied from 4.38 g/kg DM in the field established on the bare fallow to 7.97 g/kg DM in the field established on the fallow swarded with fodder galega.

3 Spring wheat

Spring wheat was grown as the third crop after the termination of the fallows, and the fallowing methods still had a strong influence on the mineral compositions of grains and straw (Table 7).

Table 7. Content of macronutrients in grain and straw of spring wheat 3 years after the end of fallowing.

Objects	Grain						Straw					
	N	P	K	Ca	Mg	Na	N	P	K	Ca	Mg	Na
	g/kg DM											
BF	20.55 [a]	4.22 [b]	3.73 [a]	0.68 [a]	0.65 [a]	0.11 [a]	4.01 [a]	1.26 [a]	7.87 [a]	1.78 [a]	0.57 [a]	0.23 [a]
NF	21.58 [a]	3.93 [a]	3.76 [a]	0.69 [ab]	0.64 [a]	0.14 [a]	5.38 [b]	1.28 [a]	9.12 [b]	2.26 [b]	0.61 [a]	0.23 [a]
FG	26.04 [b]	4.30 [b]	4.24 [c]	0.83 [d]	0.85 [b]	0.13 [a]	6.54 [c]	1.37 [b]	11.18 [d]	2.61 [b]	0.85 [b]	0.25 [a]
FG+SB	26.40 [b]	4.27 [b]	4.17 [c]	0.79 [cd]	0.78 [b]	0.12 [a]	6.42 [c]	1.36 [b]	11.15 [d]	2.57 [b]	0.80 [b]	0.25 [a]
SB	25.81 [b]	4.21 [b]	3.96 [b]	0.75 [bc]	0.78 [b]	0.13 [a]	5.54 [b]	1.25 [a]	10.03 [c]	2.23 [b]	0.62 [a]	0.24 [a]

[a–d]—significant differences at $p \leq 0.05$ between objects of experiment; BF—bare fallow; NF—natural fallow; FG—fodder galega (*Galega orientalis* Lam.); FG+SB—a mixture of fodder galega (*Galega orientalis* Lam.) with smooth brome (*Bromus inermis*); SB—smooth brome (*Bromus inermis*).

Significantly, the greatest amount of N (25.81–26.40 g/kg DM) accumulated in the grains of spring wheat grown on fields established on fallows. Significantly less N was found in the grains from fields established on bare or natural fallows (20.55 and 21.58 g/kg DM, respectively). Similar dependences were detected for the content of K, Ca, and Mg in grains. The P content of spring wheat grain varied from 3.93 to 4.30 g/kg DM. Significantly, the lowest proportion of this element was found in the grains of spring wheat cultivated on the field established on the natural fallow. Woźniak and Makarski [76] claim that the presence of leguminous plants in crop rotations does not affect the concentration of nitrogen in spring wheat grain, raising only the content of phosphorus and potassium.

As with grains, the straw of spring wheat grown on fields established on former fallows sown with fodder galega or its mixture with smooth brome had the significantly highest content of N (6.54 and 6.42 g/kg DM), while its significantly lowest content (4.01 g/kg DM) was in spring wheat straw from the field established on the bare fallow (Table 7). The straw of spring wheat grown in the third year after the termination of fallows swarded with fodder galega or its mixture with smooth brome contained significantly more P, K, Ca, and Mg than the straw from the other research objects.

3.3. Comparison of the Fallowing Methods Regarding Yield and Quality

The analysis of clusters separated two groups of technologies for keeping soil temporarily excluded from agricultural production with different effects on the yield and quality of crops grown afterwards (Figure 3). One group was composed of fallows swarded with fodder galega and fodder galega mixed with smooth brome grass. The yields of crops and the quality of yields produced by the crops grown after the fallows were turned into farmland again were approximately the same in this group. The other cluster consisted of the natural fallow and the fallow sown with smooth brome, and the differences in this group were greater.

4. Conclusions

The research results show very clearly that valuable farmland excluded from agricultural production for a long period should be protected properly. Appropriate vegetation plays a key role in maintaining soil fertility. Based on the yields of the three test crops, it can be concluded that soil should not be set aside as bare fallow. The lowest plant yields were recorded at such sites, regardless of the year of research. This solution, in the long run, leads to a reduction in soil fertility, resulting in lower yields of crops once the fallow is returned to production. The yields of plants (winter rapeseed, winter wheat, and spring wheat) grown after fallowing indicate the need for them to be properly protect. A positive impact of vegetation was recorded for as many as three years after fallow land has been established. The most effective forecrop compared to black fallow was fodder galega and its mixture with smooth brome, which, in the first year after fallow management, contributed to increases in rapeseed yield of 235 and 228%, respectively. Natural plant cover or a monoculture of grasses should not be recommended for the long-term protection of agriculturally valuable ground. This solution results in an average 30–33% increase in yields after the management of set-aside land compared to black fallow land. A far better solution, which is worth recommending, is to sow fallows with fodder galega or its mixture with smooth brome. This method of protecting set-aside fields allows, after their inclusion in production, the acquisition of more than double the yield (on average). Seeding with the mixture proposed in this research additionally eliminates the risk of reclassifying arable land into permanent grassland. In the EU, one can receive direct payments for one-time, annual mowing. Fallow land with fodder galega can also be involved in agri-environmental programs, which can significantly increase a farmer's financial benefits. In many European countries, there is a deficit of legumes, and the share of cereals in crop rotation is still too high. The soil cover incorporating fodder galega used in this experiment allowed for significantly higher yields compared to those provided by other methods of soil protection. According to the latest assumptions, agriculture should participate not only in the direct production of raw materials such as rapeseed or wheat grain but should also be deeply involved in a number of pro-environmental tasks designated as part of challenges such as the Green Deal for Europe. Fallow areas with fodder galega fit well into a landscape, provide food for pollinating insects, and provide shelter for birds and even some mammals (roe deer and hares). In this study and many previous studies on the same fallow areas, a very positive effect of fodder galega on soil fertility was proven. An area worthy of attention, which has not been fully explored, is greenhouse gas emissions and the risk of groundwater contamination as a result of the presented methods of arable land development.

Author Contributions: Conceptualization, S.S., P.J.Ż. and S.J.K.; writing—original draft, S.S. and P.J.Ż.; writing—review and editing, S.S. and J.W.; supervision, S.J.K. All authors have read and agreed to the published version of the manuscript.

Funding: This project was financially supported by the Minister of Education and Science under the program entitled "Regional Initiative of Excellence" for the years 2019–2023 (Project No. 010/RID/2018/19; amount of funding, PLN 12.000.000).

Institutional Review Board Statement: Not applicable for studies not involving humans or animals.

Data Availability Statement: All data generated or analysed during this study are included in this published article. The raw data can be made available upon request.

Acknowledgments: The results presented in this paper were obtained as part of a comprehensive research project (No. 30.610.003-110) financed by the University of Warmia and Mazury in Olsztyn, Faculty of Agriculture and Forestry, Department of Agricultural and Environmental Chemistry.

Conflicts of Interest: The authors declare no competing interests.

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