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Assessment of Beef Manure Economic Value by the Method of Equivalent Green and Mineral Fertilizer Substitution

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Abstract: The imperative of sustainable agricultural development, coupled with growing challenges related to climate change reaffirms the importance of manure and increases the demand for it. Due to the underdeveloped market for manure, there is a problem in assessing its economic value, requiring appropriate research on this topic. Thus, this research aimed to assess the manure's economic value using the method of equivalent substitution. For this purpose, the chemical composition of manure was determined by standard agrochemical analyses concerning the content of the most important mineral elements—nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O). These elements ranged from 0.49–0.60%, 0.15–1.10%, and 0.70–1.07%, respectively, and the content of organic matter ranging from 20.88 to 27.00%. Subsequently, the cost of equivalent substitution was calculated taking into account market prices for commercial fertilizers and organic matter based on the cost of an adequate quantity of white mustard—*Sinapis alba* L. fresh mass. The average cost of equivalent substitution for manure was determined to be 28.60 USD/t. The results of the applied *t*-test indicate that there is no statistically significant difference between the market prices of beef manure and the calculated prices of its substitution ($t = -1.4069$; $df = 12$; $p = 0.1848$), which implies that white mustard green manure could replace the deficit in animal-derived manure. Since both animal and green manures unambiguously should be prioritized over chemical fertilizers, future studies will reveal which other crops are applicable for further increments of green manure to make up for insufficient availability of animal manure.

Keywords: circular economy; green manure; manure pricing; organic fertilizers; soil quality; sustainability; white mustard

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1. Introduction

Productivity enhancement in agricultural production can be attained by embracing modern agricultural practices such as the utilization of natural resources, efficient irrigation, and the proper application of manure [1,2]. The utilization of manure is frequently highlighted as a 'modern agricultural practice' [3], although it is a conventional practice for soil enhancement and yield improvement. In traditional agriculture, manure served not only as the fundamental nutrient for cultivated plants but also played a crucial role in maintaining the quality of agricultural land [4–7], concomitantly exerting a positive influence on the physical, chemical, and water properties of the soil to which it is applied [8]. From an economic perspective, the utilization of manure in agricultural production is justified given its positive impact on yields [9], reaching up to a 25% of the increase [10], and extending the positive impact for up to three to five years upon application [11–14]. Furthermore, manure is increasingly becoming an alternative source of energy, owing to its application in biogas production—a technologically clean energy source [15–17].

Nevertheless, despite the clear attitude of the scientific community about the usefulness of manure application in agricultural production, some farmers were not willing to apply manure, primarily due to the high application costs [18] and the unpleasant odors that manure releases. An important precondition is the manure's responsible management, as it emits a certain amount of greenhouse gases [19], which can be reduced or eliminated with proper handling. Similarly, if optimal manure management is neglected, it can lead to environmental pollution with heavy metals, soil contamination with pathogens, and ammonia toxicity [20]. In the last few decades, however, there has been a growing demand for organizing agricultural production in a manner that ensures long-term sustainability, in which manure holds a significantly important position. This has led to, a shift in farmers' attitudes toward manure [21] and a reaffirmation of its usage [22].

Today, with greater awareness among most producers about the significance of manure in preserving soil quality, issues related to manure usage reluctance have been replaced by problems with its insufficient availability. In Serbia, the reduction in manure production is attributed to a significant decline in livestock numbers (2–3% annually) over the past two decades [23]. Data supporting this claim is the fact that out of a total of 564,541 farms in Serbia, only 1,933,840 LSU (livestock units) are found on 435,052 farms [24]. Due to availability issues, animal manure could be replaced with plant-derived sources, among which white mustard (*Sinapis alba* L.) plays a promising role (biogenic and humic substance increment, biopesticidal effect, its abundant mineral composition, organic matter content, and consequently, a favorable C/N ratio) [25]. Moreover, white mustard, regarded as a catch crop, is valuable for intercropping [26], biofumigation [27], phytoremediation [28], biofuel production [29], and as an oilseed crop [30].

Considering the significance of manure as a crucial input in agricultural production, it implies the need for an organized market where the exchange process can take place. However, there is practically no organized market for manure in Serbia or in other countries. In the USA, this is an old and persisting problem suggested to be solved by a systematic approach to market infrastructure, including the introduction of certified intermediaries, such as manure brokers and haulers, that would facilitate transactions [31]. If manure is traded, it is commonly at the local level. The reason for this situation lies in the fact that in Serbia, the majority of livestock is located on small family farms, with around 90% of manure being produced on farms with fewer than 100 LSU [19]. The market's dislocation, high costs of manure transportation and storage, as well as the traditional reluctance of workers to handle manure (due to unpleasant odors), are further exacerbated by the absence of adequate pricing frameworks for manure transactions. Since manure is a byproduct of livestock production, connected to the main product (milk, meat, eggs, etc.), and as awareness grows about its significant utility value [22], there is an increasing need to define its value, i.e., its price [32]. According to Thiery et al. [33], even in a developed country such as France, manure has no fixed 'commodity' market price but only locally defined pricing recommendations. Their research, published in April 2023, was the first attempt to estimate the economic value of manure.

One possible method for calculating the price of manure is the so-called method of equivalent substitution, which involves considering the composition of manure in terms of key macro-chemical elements (nitrogen—N, phosphorus—P_2O_5, and potassium—K_2O) and organic matter and its adequate replacement. These components are crucial for cultivated plants and soil [34,35]. The assessment of manure value using this method involves determining the prices of the mentioned elements in mineral and green fertilizers available on the market [35]. In line with the above, this study aimed to use the equivalent substitution method to assess the value of manure and compare it with the prices at which scarce manure transactions take place in the country. Thus, the specific objectives of this study were to: (i) assess the chemical composition of beef manure from three farms in the territory of Serbia; (ii) calculate the required substitution quantities of mineral and green fertilizers; and (iii) assess the substitution price of manure.

2. Materials and Methods

The equivalent substitution price, as a method for valuing manure, assumes that its value can be determined through replacement costs [34,35]. In other words, this method establishes the highest price at which manure could be traded, assuming the use of the least expensive available substitute products.

When calculating the price of manure replacement, it is necessary to take into account the chemical composition, specifically the content of the most important macro elements—nitrogen (N), phosphorus (P), and potassium (K)—in the manure. To meet the chemical characteristics of manure, a variety of products available on the market are used because there is no single product that could adequately supply the observed elements in appropriate proportions. In this study, to meet the nitrogen, phosphorus, and potassium requirements, the available mineral fertilizers UREA (46%; Promist; 446.16 USD/t), MAP (N 12% and P_2O_5 52%; Promist; 609.38 USD/t), and potassium chloride (K_2O 60%; Petrokemija d.d.; 402.63 USD/t) were used. The prices of UREA and MAP were obtained from the STIPS (STIPS—Market Information System of Serbian Agriculture. Prices of agricultural products—Ministry of Agriculture, Forestry and Water management of the Republic of Serbia) website [36]. Due to the volatility of prices for mineral fertilizers, the average price at which mineral fertilizers were traded in the period 2010–2022, in April and September, as provided by STIPS, was utilized. Since the price for potassium chloride is not available on STIPS, it was determined based on prices in retail stores for the same period.

In addition to the mineral component, organic matter constitutes a significant portion of manure, which should not be overlooked in the assessment. To satisfy the need for the content of organic matter, which, like manure, is not subject to market exchange, the cost of white mustard fresh biomass, one of the recommended crops for green manure [25,37], was calculated. When determining the green manure value, the cost of white mustard biomass was obtained by assembling an internal calculation based on acceptable agrotechnics [38]. The cost of services for performing agrotechnical measures was derived from the price list of machinery services provided by ZSV (ZSV—Cooperative Union of Vojvodina, (Price list of machinery services in agriculture, 2022)) [39]. Additionally, current market prices for necessary inputs such as seeds and mineral fertilizers were taken into account. According to all costs listed, the internal calculation yielded the following economic indicators: 270.01 USD/ha for basic inputs (seeds and fertilizers) as well as 116.00 USD/ha for basic agrotechnics (plowing 57.37 USD/ha, sowing 15.01 USD/ha, fertilizer spreading 13.06 USD/ha, and tillage 30.57 USD/ha). In the process of calculating the cost price, the average three-year yield stated by Titei [37] and Mikó et al. [40] under conditions of dry farming and semi-arid climate comparable to the environmental and production conditions in Serbia, approximately amounting to 35.4 t/ha of green biomass, was used. Taking into account the given yield and prices stated above, the calculated price for green manure (white mustard) was 10.87 USD/t. The quantities of nitrogen, phosphorus, and potassium present in the dry matter of white mustard [37], which are incorporated into the soil along with organic matter in this study, were neglected for the simplification of calculation purposes defined by the method itself.

Considering that the majority of manure produced in Serbia comes from large livestock [19], samples of beef manure were collected for the purpose of this research. The samples were collected from three beef farms, and the selection of farms was made as realistically as possible to represent the actual state regarding the differences in the applied practices (composted, semi-composted, or fresh manure) and subsequently the quality of manure. The sample collected from the first farm in Vrbas is labeled as VS, the second sample collected from Bačka Topola is labeled as BT, and the third sample from Novi Bečej is labeled as NB.

During the sampling, manure was collected evenly across the width, length, and depth of the manure pile [41]. A substantial number of samples, on average 20, were taken from each farm. These were combined to create a separate sample weighing 10 kg. From this composite core sample, after homogenization, mixing, and dividing into quarters (by random selection), a final 2 kg sample was obtained for chemical analysis [41]. Chemical analysis was performed in the soil, fertilizer, and plant material testing laboratory at the Department of Agrochemistry, Faculty of Agriculture in Novi Sad. The dry matter content was determined gravimetrically after drying the samples to a constant weight (70 °C for 24 h). Organic matter content was determined after incineration (loss on ignition) in an oven after 5 h at 550 °C. The total C, N, and C/N contents were determined using a CHNS analyzer (Elementar Vario EL, GmbH, Hanau, Germany). The phosphorus content (P_2O_5) was determined in the extract via the molybdenum blue method spectrophotometrically (Shimadzu, UV-2600, Kyoto, Japan), and the K_2O content by flame photometry (Jenway 6105, Essex, UK), as in detail explained by Kovačević et al. [42].

Due to the absence of an organized market and records of market prices for comparison purposes, the prevailing market price at which scarce manure transactions take place was determined through telephone interviews with 11 farmers. To ensure a more objective assessment, both sellers and buyers of manure were contacted, and in selecting the farmers for interviews, measures were taken to include representatives from the basic set as much as possible.

Given that the effectiveness/accessibility of nutrients from manure and the proposed substitutes are not equal, the methodology provided by Marko et al. [34] was used in the calculation (Equations (1)–(5)), requiring both mineral and organic fertilizers to be taken into account.

The calculation of the substitution quantity for N was performed using Equation (1).

$$Q_N = ((A - B)/C_N) \times 100 \quad (1)$$

where Q = substitution quantity; A = quantity to be compensated by substitution; B = the amount of N that was replaced from MAP; and C = active substance.

The calculation of the substitution quantity for P_2O_5 was performed using Equation (2).

$$Q_P = (A/C_P) \times 100 \quad (2)$$

where Q = substitution quantity; A = quantity to be compensated by substitution; and C = active substance.

The calculation of the substitution quantity for K_2O was performed using Equation (3).

$$Q_K = (A/C_K) \times 100 \quad (3)$$

where Q = substitution quantity; A = quantity to be compensated by substitution; and C = active substance.

The calculation of the substitution quantity for Organic matter was performed using Equation (4).

$$Q_{OM} = (A/C_{OM}) \times 100 \quad (4)$$

where Q = substitution quantity; A = quantity to be compensated by substitution; and C = active substance.

The calculation of the substitution price for each of the investigated parameters was performed using Equation (5).

$$SP = Q \times P \quad (5)$$

where Q = substitution quantity of nitrogen, phosphorus, potassium, and organic matter, respectively; P = market price of fertilizers.

In the analysis of the collected data, the descriptive statistics method was initially used. Then, to compare the samples collected from three farms, a comparison of their chemical elements was performed using analysis of variance (ANOVA), and the Duncan post-hoc test was applied to determine between which treatments there are statistically significant differences.

Subsequently, the difference between the market prices of manure and the calculated prices for manure substitutes was tested using a *t*-test for the difference between the two means. The *t*-test for the difference between two means is based on the assumption of equality of the means of the observed samples, while the alternative hypothesis of this test is that there is a statistically significant difference between the observed sample means. The advantage of this test is its applicability even with extremely small samples, and it is sensitive to high effect size [43]. All the obtained data were statistically processed using STATISTICA 14 software (Tibco, Palo Alto, CA, USA).

3. Results and Discussion

3.1. Manure Chemical Analysis

The results of the manure chemical analysis from three samples collected from three farms in the territory of the Republic of Serbia are presented in Table 1. Nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) content were in a range of 0.49–0.60%, 0.15–1.10%, and 0.70–1.07%, respectively, while the organic matter and consequent C/N ration varied from 64.55 to 74.07% and from 13.84 to 14.75.

Table 1. Results of chemical analysis of beef manure from three farms in the territory of Serbia.

Sample	Nitrogen (N) % *	Phosphorus (P_2O_5) %	Potassium (K_2O) %	Moisture (%)	Organic Matter (%)	C/N Ratio
VS	0.60	0.35	1.07	64.55	26.51	13.84
BT	0.49	0.15	0.73	74.07	20.88	14.49
NB	0.60	1.10	0.70	68.30	27.00	14.75

*—in the total fresh weight.

A Duncan posthoc test for the obtained results of the chemical analysis unambiguously indicates that the analyzed samples have a significantly different chemical composition.

Based on ANOVA results, statistically significant differences in all investigated chemical elements were observed between samples collected from three different farms. As evident from the data presented in Table 2 and the Duncan's test, differences between the samples are less pronounced in terms of nitrogen content compared to phosphorus and potassium content. The organic matter and moisture content in all three samples also differ statistically significantly ($p < 0.05$). The significant differences between individual samples likely stem from the varying management practices of manure on the observed farms (fresh, semi-composted, and composted). These differences certainly highlight the importance of the research, considering that beef farms in Serbia are highly heterogeneous in various observed characteristics, including manure management, so in line with that, the sample effectively represents the situation in the sector.

Veljković et al., point out that the manure content is significantly different from sample to sample [44]. These authors state that on average, 1 ton of beef manure contains about 0.5% nitrogen, 0.25% phosphorus and 0.6% potassium, while the average content of organic matter is 18%. The determined nitrogen content in individual samples in this study does not deviate significantly from their results, while values for phosphorus and potassium differ considerably, especially in some samples. All the samples analyzed in this research have a higher content of organic matter compared to the statements of the mentioned authors. Similarly, varying chemical element contents in individual manure samples are noted by Kostić et al. [45]. Concomitantly to other authors, they explain the differences by the origin of the manure [46], feeding practices, the type and proportion of bedding mat [47], storage conditions [48], and other factors. Also, the authors emphasized that significant losses of certain elements can also occur due to poor manure management [45,47]. Köninger et al. [49] showed that manure quality is more important than manure quantity, influencing both the soil and the general environment. In this regard, C/N ratios, significant for the mineralization cycle of the organic matter and their ability to supply soil with nutrients in the long term, were comparable in both the green manure chosen (white mustard) and the animal-derived manure, taking values from 13.8 to 14.8 and aligning with an average from the literature of 14.7 [37] and 16.7 [25].

Table 2. Results of the ANOVA and Duncan test.

	Effect	SS	df	MS	F	*p*-Value	Duncan Test			
								VS	BT	NB
N	Intercept	3.7576	1	3.7576	62,194.79	0.0000	VS	/	S *	NS
	Treatment	0.0323	2	0.0162	267.97	0.0000	BT	S	/	S
	Error	0.0005	9	0.0001			NB	NS	S	/
P_2O_5	Intercept	3.4111	1	3.4411	119,575.7	0.0000	VS	/	S	S
	Treatment	1.9972	2	0.9986	34,701.2	0.0000	BT	S	/	S
	Error	0.0002	9	0.0001			NB	S	S	/
K_2O	Intercept	8.3067	1	8.3067	11,938.9	0.0000	VS	/	S	S
	Treatment	0.3371	2	0.16685	3855.4	0.0000	BT	S	/	S
	Error	0.0004	9	0.0001			NB	S	S	/
C/N ratio	Intercept	3095.729	1	3095.729	13,861,475	0.0000	VS	/	S	S
	Treatment	2.151	2	1.075	4815	0.0000	BT	S	/	S
	Error	0.003	9	0.000			NB	S	S	/
Moisture	Intercept	57,087.85	1	57,087.85	428,158,864	0.0000	VS	/	S	S
	Treatment	183.60	2	91.80	688,502	0.0000	BT	S	/	S
	Error	0.0001	9	0.0001			NB	S	S	/
Organic matter	Intercept	7377.008	1	7377.008	3,242,641	0.0000	VS	/	S	S
	Treatment	92.757	2	46.379	20,386	0.0000	BT	S	/	S
	Error	0.0200	9	0.0020			NB	S	S	/

*—Statistically significant differences are marked with the letter S, while non-significant differences are marked as NS.

3.2. Calculation of the Required Substitution Quantities

Based on the obtained chemical analysis, the next step involved calculating the quantity of different mineral fertilizers and green manure that represents an equivalent substitute for the manure whose samples were collected and analyzed.

As described in detail in the materials and methods section, to satisfy the macronutrients' needs, the mineral nitrogen fertilizer 'UREA' (46% N), phosphorus 'MAP' or monoammonium phosphate (52% P_2O_5), and potassium 'KCL', i.e., potassium chloride (60% K_2O), were used. As a substitute for organic matter in manure, green manure, specifically white mustard, was applied. Apart from being used as a crop for oil production, white mustard also finds application as a cover crop for green manure during the interseasonal period [29,37,50,51]. The calculation based on the organic matter content in white mustard, which is 20.5% by Titei [37], yielded the results presented in Table 3. Equivalent substitutions for 100 kg of manure are presented for individual samples. Taking into account the proportions of nitrogen, phosphorus, potassium, and organic matter in the manure while considering their effects on substitution according to Marko et al. [34], the required quantities of active substances to be substituted from replacement fertilizers amounted to 0.24, 0.35, 1.07, and 31.81 kg for N, P_2O_5, K_2O, and organic matter, respectively. In the next step, based on the quantity of active substances contained in commercial fertilizers or the organic matter of green manure, the necessary amount of replacement fertilizer was determined.

Considering that the product used to fulfill phosphorus is MAP, a commercial fertilizer that contains 12% nitrogen in addition to phosphorus, this was taken into account in the calculation. Therefore, the amount of nitrogen supplied by nitrogen fertilizer was proportionally reduced. For example, in Sample VS, the amount of phosphorus from 100 kg of manure is replaced with 0.67 kg of MAP, providing 0.08 kg of nitrogen. Consequently, the quantity of nitrogen supplied by nitrogen fertilizer is reduced by that amount. The quantities of mineral and green manure that substitute for 100 kg of manure were determined using the same principle for Samples BT and NB.

Table 3. Equivalent replacement of 100 kg of manure.

Parameter	Share in Manure (%)	Effect Coeff.	Required Quantities in Replacement (kg)	Quantities that Replace 100 kg of Manure
		VS		
N	0.60	0.4	0.24	$\frac{(0.24-0.08)\times 100}{46} = 0.35$ kg
P_2O_5	0.35	1.0	0.35	$\frac{0.35\times 100}{52} = 0.67$ kg
K_20	1.07	1.0	1.07	$\frac{1.07\times 100}{60} = 1.78$ kg
Organic matter	26.51	1.2	31.81	$\frac{31.81\times 100}{20.50} = 155.17$ kg
		BT		
N	0.49	40	0.20	$\frac{(0.20-0.03)\times 100}{46} = 0.37$ kg
P_2O_5	0.15	100	0.15	$\frac{0.15\times 100}{52} = 0.28$ kg
K_20	0.73	100	0.73	$\frac{0.73\times 100}{60} = 1.22$ kg
Organic matter	20.88	120	25.06	$\frac{25.06\times 100}{20.50} = 122.24$ kg
		NB		
N	0.60	40	0.24	$\frac{(0.24-0.25)\times 100}{46} = 0.00$ kg
P_2O_5	1.10	100	1.10	$\frac{1.10\times 100}{52} = 2.11$ kg
K_20	0.70	100	0.70	$\frac{0.70\times 100}{60} = 1.16$ kg
Organic matter	27.00	120	32.4	$\frac{32.40\times 100}{20.50} = 158.05$ kg

As can be seen from the data presented in Table 2, due to the significantly higher phosphorus content in Sample NB, the total equivalent quantity of nitrogen already present in the fertilizer would be supplied from the replacement fertilizer 'MAP', eliminating the need for additional nitrogen fertilizer.

Given the significant differences in the chemical composition of manure, to meet the needs of the soil with a certain amount of nutrient elements from the manure, it is necessary to fertilize with different norms. Better quality manure, with a higher content of nutrients, enables a lower rate of fertilization (t/ha). Given that the costs of transportation when using manure are very high and affect the willingness of farmers to apply it [18], it is in the interest of producers to use manure of better quality.

The calculated results indicate that, for the substitution of 100 kg of manure in Sample VS, it requires 155.17 kg of green mass and a 2.80 kg mixture of mineral fertilizers; for Sample BT, it requires 122.24 kg of green mass and a 1.87 kg mixture of mineral fertilizers; and for Sample NB, it requires 158.05 kg of green mass and a 3.27 kg mixture of mineral fertilizers. The lower replacement values for Sample BT are expected because of the higher moisture content in this sample.

3.3. The Manure Substitution Price Valuation

In addition to the intrinsic features obtained the process of valuing manure requires including the market prices of the involved mineral fertilizers and the cost of white mustard, as explained in the Methodology section. Table 4 illustrates the calculation of the replacement cost value for manure for all three individual samples.

Table 4. Manure replacement price assessment based on substitution prices and quantities.

Fertilizer	Substitution Quantitiy (%)			Price (USD/t)	Manure Value (USD/t)		
	SAMPLE				SAMPLE		
	VS	BT	NB		VS	BT	NB
UREA (46%)	0.35	0.37	0.00	446.16	1.57	1.65	0.00
MAP (52%)	0.67	0.28	2.11	609.38	4.11	1.72	12.94
KCL (60%)	1.78	1.22	1.16	402.63	7.11	4.88	4.64
Organic matter	155.17	122.24	158.05	10.87	16.86	13.28	17.17
Total (USD/t)	/	/	/	/	29.64	21.52	34.75

On average, the value of manure from all three samples was 28.60 USD/t, with significant variations depending on the sample and reflecting differences in the manure composition. Figure 1 illustrates the average contribution of individual elements in the structure of the estimated value of manure for all three observed samples.

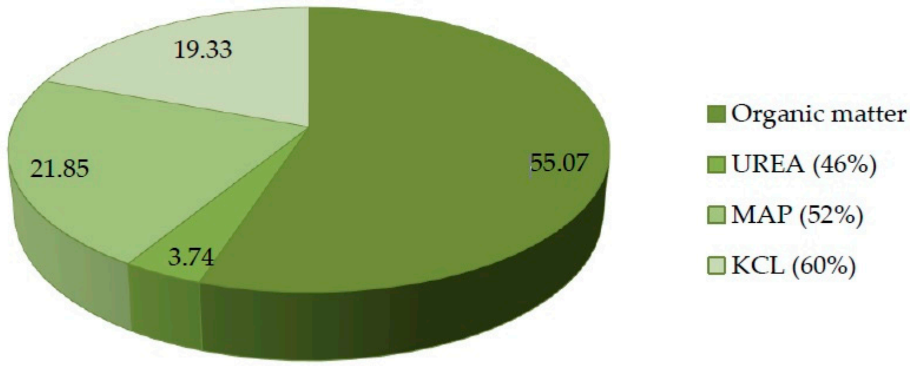

Figure 1. Share of N, P, K, and organic matter in the value of manure, %.

The largest share in the assessed economic value of manure is organic matter, accounting for 55.07%. Therefore, any changes related to the selection of green manure, including its cost, whether in terms of changes in production costs or changes in an achieved yield, can cause significant fluctuations in the value of the manure, urging further research and the search for feasible and cost-effective crops.

In this calculation, average yields obtained in the literature [37,40] were used. However, Erić et al. [38] emphasize that the yield of certain varieties and genotypes of white mustard can reach significantly higher yields of green mass, up to 50–60 t/ha, at the same production costs, which can significantly direct future breeding goals and application for white mustard.

The determined value of manure using the equivalent substitution method, at 28.60 USD/t, is significantly higher than the value reported by Veljković et al. [44]. According to them, the market value of beef manure in Serbia averaged between 4.65 and 5.57 USD/t. The authors emphasized that, under free agreement conditions, this price often reached a value of 9.28 USD/t. Investigating short- and long-term floor and ceiling prices for manure in a crop and livestock farm exchange, Thiery et al. [33] simulated farmyard manure prices varying from 0 to 21.76 USD/t to identify the manure ceiling price compared to purchasing mineral fertilizer only and plowing back straw. Their iteration led to the conclusion that for French farmers in a conventional field crop system, an acceptable manure price should be between 10.88 USD/t in the short term and 19.59 USD/t in the long term. Through interviews with farmers conducted in 2022 and 2023, it was found that the market value of manure at the seller's farm generally ranges from 6.50–14.52 USD/t. However, due to the farmer's tendency to use the produced manure to fertilize their own fields as much as possible [52], there is a pronounced shortage of manure. In conditions of high demand and free agreement, the market price can reach up to 18.56 USD/t of manure.

As the calculated value of manure's equivalent substitution includes all the costs of introducing mineral and green fertilizers into the soil, to compare the sales value with the estimated value of equivalent substitution, it is necessary to add the costs of loading, transportation, spreading, and plowing into the soil to the determined market value of manure. The costs of logistics and plowing manure into the soil depend on the level of mechanization of the farm [53], which buys or sells manure. According to that, if the agreement implies that the seller handles the manure, this cost is usually around 150% of the agreed (market) manure price. In that case, the estimated value of plowed manure ranges from 23.21–32.49 USD/t, which aligns with the calculated equivalent value. The results of the applied *t*-test on small samples indicate that there is no statistically significant difference between the market prices of manure and the calculated prices of manure substitution ($t = -1.4069$; df = 12; $p = 0.1848$, Table 5).

Table 5. Results of the *t*-test comparing the market prices of manure and the calculated prices of manure substitution.

Actual Beef Manure Price	Equivalent Substitution Price	t-Value	df	*p*
24.35	28.60	−1.40698	12	0.184802

The absence of statistically significant differences between the final prices implies that white mustard green manure could replace the current deficit of animal-derived manure, contributing to numerous environmental hazard reductions, such as nitrogen leaching and water pollution [54]. Aligning with the European Union's Circular Economy Action Plan [55], which encourages the utilization of nutrients from manure and other organic sources to replace chemical fertilizers, and the New European Union's (EU) Common Agricultural Policy 2023–2027 (CAP) [56], which strives to align agriculture more closely with the objectives of the Field to Fork strategy, there is a need for reducing nutrient pollution [57]. Thus, the replacement of chemical fertilizers with green manure is gaining more and more attention and has been highlighted in very recent studies. In China, Ma et al. [58] found that even the partial organic substitution of chemical fertilizers with organic fertilizers from rapeseed cake manure better fitted the nutrient demand of perennial tea plants to ensure good quality, high economic profits, and reduced environmental risks. Furthermore, Castrunovo et al. [59] and Tasci and Kuzucu [60] showed that the use of green manure organic amendments positively affects vegetable production, enhancing both quality and profitability. In addition to all mentioned, white mustard researched in our paper possesses another extremely important 'green solution' added value. Namely, it was proven that its application and processing reduce some of the most problematic soil-borne diseases [61–64] and pests, especially nematodes [65,66].

After accounting for all the positive environmental effects and calculating statistically non-significant differences in economic value, both animal and green manure should be given priority over chemical fertilizers. Future research should focus on improving the calculation methodology to provide farmers with simple, accurate, and easily applicable formulas as a tool for their decision-making purposes. Furthermore, decisions should be supported by manure cost-efficiency calculations, due to the significant impact of transportation-allocation costs on manure marketability and application [18,62]. In this regard, it is crucial to manage manure optimally in order to produce high-quality fertilizer. This approach meets the manure quality needs with significantly lower quantities—fertilization rates per unit area (t/ha). Thus, although higher-priced manure is utilized, the application of lower fertilization rates reduces transport costs and thus overcomes the difficulties in manure application, which were highlighted by MacDonald [18] and Du et al. [67].

4. Conclusions

The method of equivalent substitution applied to determine the economic value of the beef manure revealed that its average economic value is 28.60 USD/t. Approximately 145 kg of green manure and 2.65 kg of mineral fertilizer are needed to replace 100 kg of beef manure. Organic matter has the highest contribution to the total economic value of manure (55.07%). With this research, we confirmed our initial hypothesis that the economic value of beef manure estimated by the method of equivalent substitution is not significantly different from the traded price at local markets. Also, the absence of a statistically significant difference between the cost of manure and its substitutes suggests the economic justification of replacing deficit animal-derived manure with green manure, available to farmers in their immediate vicinity.

As with all other research, this one also has certain limitations. In the current form, the calculated economic value of manure to some extent underestimates the long-term positive effects since the chosen method of assessment considers only the content of nutrients and organic matter, thus focusing on the direct benefits and nutrient availability in a short-term manner (up to three to five years upon application). Mid- and long-term benefits in terms of the improvement in soil physical properties are neglected in the calculation, assuming that the farmers are aware of them. Moreover, future research should include an assessment of not only organic matter from white mustard but also the values of valuable chemical elements in it (N, P_2O_5, K_2O, Cu, Mn, Zn, Mg, and Fe).

Nevertheless, the presented model contributes to sustainable strategies in soil fertility management and could be a useful initial tool for decision-making purposes that can be further enhanced in future research. Due to, on the one hand, the significant variability in manure quality and, on the other hand, the volatility in substitute fertilizer prices, determining the value of manure is an ongoing challenge. Since both animal and green manure unambiguously should be prioritized over chemical fertilizers and showed statistically non-significant cost differences, future studies will reveal which other crops are applicable in further increments of green manure to replace insufficiently available animal manure.

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