



Effects of organic fertilizer applications on marketable yield and tuber size distribution in potato

Esengül ERİM BASTEM¹ , Erdoğan ÖZTÜRK^{1,*} 

¹Atatürk University, Faculty of Agriculture, Department of Field Crops, Erzurum/TÜRKİYE

*Corresponding author: erozturk@atauni.edu.tr

Received: 22/02/2026, Accepted: 09/06/2026

Abstract

This study aimed to determine the effects of individual and combined applications of different organic fertilizers on marketable tuber yield and tuber size distribution of potato grown under high-altitude ecological conditions over two growing seasons (2020-2021). In the experiment, cattle (C), sheep (S), vermicompost (V), and poultry (P) manures were applied either individually or in specific combinations. The results indicated that fertilizer treatments significantly affected total yield, marketable yield, and tuber size distribution in both years. Generally, combined applications outperformed individual applications. Specifically, the highest marketable tuber yield (22.0 t ha⁻¹) and marketable tuber proportion (87.9%) were obtained from the T16 treatment. While the highest large tuber yields were recorded in T13 (14.3 t ha⁻¹) and T16 (13.5 t ha⁻¹) treatments, the maximum medium and small tuber yields were found in T11 (9.6 t ha⁻¹) and T4 (3.7 t ha⁻¹) treatments, respectively. Increasing the number of organic fertilizers applied in combination enhanced the proportion of marketable and large tubers while reducing the proportion of small and cull tubers. The application of cattle, sheep, vermicompost, and poultry manures at 25% each of their recommended doses (T16 - C×S×V×P) provided the highest marketable tuber yield and the most balanced size distribution among all treatments. In this treatment, the proportion of marketable tubers reached 87.9%, whereas the cull tuber ratio decreased to 3.6%. The combined use of diverse organic fertilizers enhanced nutrient availability and tuber bulking, providing a sustainable strategy to improve both productivity and market quality in high-altitude potato production. These findings suggest that in high-altitude ecological conditions, the complementary use of diverse organic fertilizers with different characteristics instead of a single fertilizer source is a sustainable and effective method for both yield and market quality.

Keywords: Potato, *Solanum tuberosum*, Organic fertilization, Vermicompost, Poultry, Sheep, Cattle, Tuber size, Marketable yield

Please cite this article as follows:

Erim Bastem, E., & Öztürk, E. (2026). Effects of organic fertilizer applications on marketable yield and tuber size distribution in potato. *Journal of Biometry Studies*, 6(1), 16-25. <https://doi.org/10.61326/jofbs.v6i1.02>

1. Introduction

Potato is a strategic product in global agricultural systems due to their high yield potential and versatile uses, as well as being a primary source of carbohydrates for a significant portion of the world's population. Tubers have a rich nutritional profile, with high energy content, approximately 2.1% protein, starch constituting 75-80% of dry weight, carbohydrates, vitamins C and B, and various mineral elements (Devaux et al., 2014; Ingallina et al., 2020). Owing to these attributes, potatoes have been reported as the fifth most produced

agricultural product in the world after sugar cane, maize, rice, and wheat (FAO, 2022).

In recent years, increasing population and food demand have placed potato production at the centre of food security, particularly in developing countries (Vilvert et al., 2022). However, the long-term and intensive use of chemical fertilizers to achieve high yields has caused serious environmental problems such as soil structure degradation, reduced organic matter content, and weakened soil biological activity (Hargreaves et al., 2008; Seaman, 2011). These negative impacts have



necessitated sustainable agriculture approaches and alternative nutrient management strategies. In this context, the use of organic fertilizers stands out as an important option in terms of both environmental sustainability and product quality. Numerous studies have reported that organic fertilizers improve soil structure, increasing its aeration and water retention capacity, promoting microbial activity, and contributing to a more balanced supply of plant nutrients (Leytem & Westermann, 2005; Perez et al., 2007; Ahmad et al., 2023). Consequently, the impact of organic fertilization on the yield and quality of potato has become a focal point of intensive research in recent years.

Among animal-based organic amendments, vermicompost (worm castings) is distinguished by its high biological activity and its capacity to enhance the bioavailability of essential plant nutrients. Research indicates that vermicompost applications promote vegetative growth, increase total tuber yield, and improve the percentage of marketable tuber in potato, while also positively influencing tuber size and size distribution (Yourtchi et al., 2013; Kmeťová et al., 2013). Similarly, El-Sayed et al. (2014) demonstrated that organic fertilizer applications lead to significant increases in both total and marketable tuber yields. Poultry manure has likewise been extensively investigated in potato cultivation, primarily due to its substantial nitrogen and phosphorus concentrations. Zandian et al. (2015) reported that poultry manure applications enhanced both the number and weight of tubers within the 25-35 mm diameter range, thereby improving marketable tuber yield. Furthermore, Hussain et al. (2024) documented those various organic fertilizers increased tuber diameter, an effect directly correlated with the nutrient profile of the amendments. Investigations involving leonardite and other organic materials have similarly reported substantial gains in marketable tuber yield (Şanlı et al., 2013). Blecharczyk et al. (2023) demonstrated that in cold environments, low temperatures decelerate nutrient release from organic fertilizers, which fails to satisfy the requirements of potato production and paradoxically results in yield losses. Walia et al. (2023) reported that potato yield under organic fertilizer application increased by approximately 19.79% compared to the sole chemical fertilizer treatment, and within a certain range, the yield increased progressively with the application rate of organic fertilizer. Despite potato can grow in any soil, the crop will perform better if the soil is rich with organic matter (Edwards & Arancon, 2022).

Despite the extensive research conducted on the utilization of organic fertilizers in potato production, there is a paucity of studies that comparatively assess

the effects of diverse animal-based organic fertilizers on tuber size distribution and commercial quality. However, tuber size distribution is a quality criterion as decisive as total yield in terms of potato marketability and economic value. The objective of this study is to ascertain the impact of utilizing diverse animal-derived organic materials, including worm, chicken, cattle, and sheep manure, as fertilizers in potato cultivation, on the distribution of tuber size and commercial quality. The study is to contribute to the existing literature on this subject by determining the effects of different types of organic fertilizer and the manner of its application on the marketable tuber ratio of potato.

2. Material and Method

This research was conducted during the summer growing seasons of 2020 and 2021 at the experimental field of the Plant Production Application and Research Center, Atatürk University, Erzurum, Türkiye, to evaluate the effects of various organic fertilizer types and application methods on potato tuber size and tuber size distribution. The experimental site, a high-altitude region situated at an elevation of 1853 m above sea level, is characterized by a continental climate. The region experiences significant diurnal temperature fluctuations, with cold and snowy winters and a notably short growing season. Air temperature, rainfall, and relative humidity during the crop-growing period (May–September) are presented in Figure 1. During both experimental seasons, the average air temperature remained above the long-term average (15.2 °C), reaching 16.5 °C in 2020 and 17.1 °C in 2021. Significant variability was observed in the amount and distribution of precipitation. While the 2020 growing season received considerably higher rainfall (234.6 mm) than the long-term average (180.4 mm), the 2021 season was notably drier, with a total precipitation of only 121.6 mm. During the study years (2020 and 2021), soil analysis of the research area revealed sand contents of 32.1% and 33.7%, silt contents of 36.8% and 46.7%, and clay contents of 26.7% and 29.2%, respectively. The soil texture was identified as clay-loam, with pH values measured at 7.4 and 7.2. In the experimental site soils, where organic matter levels were 1.39% and 1.15%, total nitrogen (N) was determined as 0.07% and 0.06%. Additionally, plant-available phosphorus (P_2O_5) and potassium (K_2O) were measured at 6.6–5.3 kg da⁻¹ and 230.8-220.5 kg da⁻¹, respectively. Consequently, the soils were characterized as slightly alkaline, with low levels of total nitrogen, available phosphorus, and lime, and very low organic matter content; conversely, they were found to be rich in plant-available potassium (Sezen, 1991).

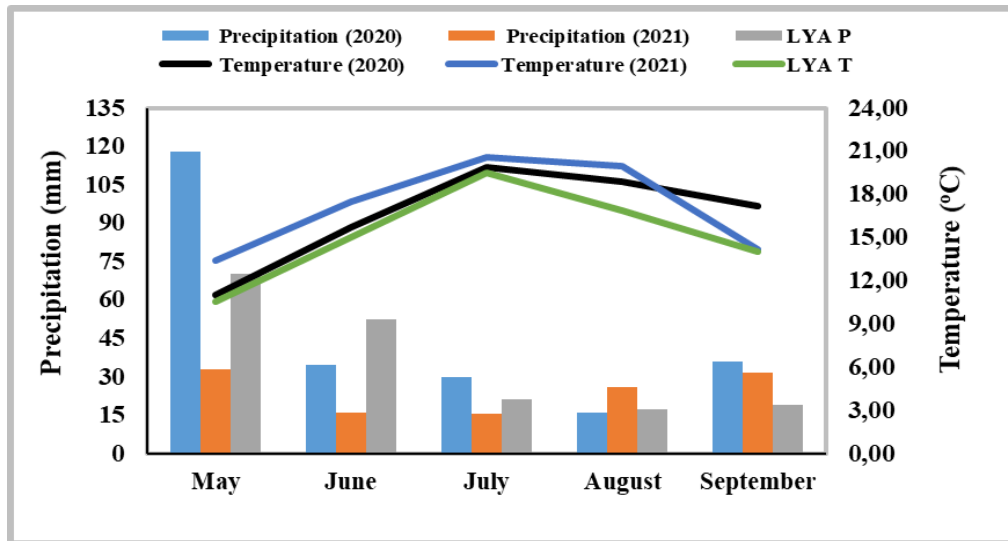


Figure 1. Precipitation and air temperature at the experimental area in the eastern Türkiye in 2020 and 2021 (LYAP: Long-year average precipitation; LYAT: Long-year average temperature)

In the study, the potato cultivar Agria, characterized by high yield potential, medium-to-late maturity, and long-oval tubers with yellow skin and flesh color, was used as plant material. In addition, cattle manure (3 t da⁻¹; 1.64% N, 0.69% P₂O₅, and 0.3% K₂O), sheep manure (2 t da⁻¹; 4.0% N, 0.6% P₂O₅, and 2.9% K₂O), poultry manure (1 t da⁻¹; 25% organic matter, 2% N, 1.91% P₂O₅, 1.88% K₂O, and 37% moisture), and vermicompost (200 kg da⁻¹; 65.5% organic matter, 1.1% N, 30% humic–fulvic acids, 1.5% K₂O, 0.7% P₂O₅, 23% moisture, pH=8.1) were applied as organic fertilizer sources in the experiment.

The experiment was conducted in a Randomized Complete Block Design with three replications (Yıldız, 1994). Organic fertilizers were applied both individual and in specific combinations, uniformly distributed and incorporated into the soil during the plot layout process before planting. Detailed information on the amounts and combinations of the organic fertilizers used is provided in Table 1. Planting was performed on May 4 and 14, 2020 and 2021, at a spacing of 70 cm between rows and 35 cm within rows. To prevent the mixing of fertilizers between treatments, the plots were organized into basins.

Once the plants reached a height of 5–10 cm following emergence, the first hoeing was performed. Approximately 20–25 days later, a second hoeing was carried out, including earthing-up (hilling) applications. Irrigation was initiated at the onset of the flowering stage via the furrow irrigation method. Depending on climatic and soil conditions, the crop was irrigated four times in the first year and six times in the second year, the latter due to higher temperatures and insufficient precipitation. Furthermore, weed control was maintained throughout the growing season through both

hoeing and manual weeding. The harvest was conducted between September 24 and 28 in 2020 and 2021, when the foliage turned yellow and dried, stolons detached from the mother plant, and tubers reached a specific size with a firm (non-peeling) skin.

Table 1. Details of treatments used in the experiment in 2020 and 2021

Treatment	Fertilizer and treatment combination	Fertilizer combination ratios
T ₁	Control	No fertilizer applied
T ₂	Cattle Manure (C)	100%
T ₃	Sheep Manure (S)	100%
T ₄	Vermicompost (V)	100%
T ₅	Poultry Manure (P)	100%
T ₆	C×S	50%+50%
T ₇	C×V	50%+50%
T ₈	C×P	50%+50%
T ₉	S×V	50%+50%
T ₁₀	S×P	50%+50%
T ₁₁	V×P	50%+50%
T ₁₂	C×S×V	33.3%+33.3%+33.3%
T ₁₃	C×S×P	33.3%+33.3%+33.3%
T ₁₄	C×V×P	33.3%+33.3%+33.3%
T ₁₅	S×V×P	33.3%+33.3%+33.3%
T ₁₆	C×S×V×P	25%+25%+25%+25%

The harvested tubers were graded into four size classes using 5.0, 3.5, and 2.8 cm sieves: large (>5.0 cm), medium (3.5–5.0 cm), small (2.8–3.5 cm), and cull (<2.8 cm). Additionally, tubers with a diameter exceeding 35 mm were classified as marketable tubers. These graded tubers were first weighed individually to determine plot yields, which were then used to calculate the yield per hectare (t ha⁻¹) for each size category.

Furthermore, the weight-based proportions of these size-graded tubers within the total yield were determined and expressed as percentages (%).

Data were analyzed using the SPSS package (SPSS, Version 20.0, SPSS Inc, Chicago, IL, USA). When the F-test indicated statistical significance at the $p=0.05$ level, the protected least significant difference (Protected DUNCAN) was used to separate the means (Steel & Torrie, 1980).

3. Results

Marketable tuber yield (>3.8 cm), large tuber yield (>5.0 cm), medium tuber yield (3.5-5.0 cm), small tuber yield (2.8-3.5 cm), and cull tuber yield (<2.8 cm) were statistically significant at the $p<0.01$ level between years. The application of organic fertilizers, applied either individual or in combination, significantly affected ($p<0.01$) the yields of different tuber size classes, particularly marketable tuber yield, whereas no significant effect was observed on cull tuber yield. Furthermore, tuber size distribution was not significantly influenced by the organic fertilizer treatment \times year interaction (Table 1).

3.1. Marketable tuber yield (>3,8 mm) and proportion of the total tuber yield

Marketable tuber yield was 24.2 t ha⁻¹ in 2020, accounting for 92.3% of the total tuber yield; however, it declined to 11.1 t ha⁻¹ in 2021, representing 66.5% of the total yield. The application of organic fertilizers, either alone or in combination, resulted in significant differences in marketable tuber yield and tuber size distribution in potato. Marketable tuber yields ranged from 12.8 to 22.0 t ha⁻¹ across treatments, with combined organic fertilizer applications generally producing higher yields than individual applications. The highest marketable tuber yield was recorded in the T16 (C \times S \times V \times P) treatment (22.0 t ha⁻¹), which also exhibited the greatest proportion of marketable tubers within the total yield (87.9%). This treatment was followed by T11 (V \times P) (20.5 t ha⁻¹) and by T13 (C \times S \times P) and T12 (C \times S \times V), with yields ranging from 19.9 to 20.1 t ha⁻¹. The proportion of marketable tubers in these treatments varied between 82% and 85%, indicating that the combined use of different organic fertilizers positively influenced both tuber yield and marketable quality. Among the individual organic fertilizer treatments, T5 (P) resulted in a notable increase in marketable tuber yield (20.0 t ha⁻¹) compared with the control (13.9 t ha⁻¹). In contrast, cattle (T2), sheep (T3), and vermicompost (T4) applications produced moderate yields ranging from 17.2 to 18.3 t ha⁻¹. The lowest marketable tuber yields were observed in T8 (C \times P) and the control treatment

(T1), with 12.8 and 13.9 t ha⁻¹, respectively (Table 2, Figure 2).

3.2. Tuber yields across various size categories

Large tuber yield was 18.5 t ha⁻¹ in 2020, accounting for 68.6% of the total tuber yield; however, it declined sharply to 2.9 t ha⁻¹ in 2021, representing only 17.4% of the total yield. Significant differences were observed among organic fertilizer treatments and their combinations regarding large tuber yield. The highest large tuber yields were obtained from T13 (C \times S \times P) and T16 (C \times S \times V \times P), with 14.3 and 13.5 t ha⁻¹, respectively. These treatments also exhibited the highest proportions within the total tuber yield at 60.7% and 53.9%. Treatments T5 (P), T6 (C \times S), T10 (S \times P), and T12 (C \times S \times V) provided moderate-to-high yields, with large tuber proportions ranging approximately between 49% and 54%. In contrast, the lowest large tuber yield was recorded in T8 (C \times P) at 7.0 t ha⁻¹ (41.5%). In the control treatment, large tuber yield was 8.4 t ha⁻¹, accounting for 47.2% of the total yield (Table 2, Figure 2). Overall, multi-organic fertilizer combinations enhanced both large tuber yield and its relative proportion compared to single applications.

Medium tuber yield (3.5–5.0 cm) was 6.4 t ha⁻¹ in 2020, accounting for 23.8% of the total tuber yield, whereas it increased to 8.2 t ha⁻¹ in 2021, representing 49.1% of the total yield. Among the organic fertilizer treatments, the highest medium tuber yield was recorded in T11 (V \times P) (9.6 t ha⁻¹; 38.6%). This was followed by T4 (V), T2 (C), and T3 (S), with yields ranging from 8.1 to 8.4 t ha⁻¹. In contrast, relatively lower medium tuber yields were observed in T1 (Control) and T6 (C \times S) (Table 1, Figure 2). Overall, the marked increase in the proportion of medium-sized tubers, particularly in the second year, suggests that medium tuber formation becomes more pronounced under environmental stress conditions that restrict tuber bulking.

Small tuber yield (2.8-3.5 cm) was 1.3 t ha⁻¹ in 2020, accounting for 4.7% of the total tuber yield, whereas it increased to 4.2 t ha⁻¹ in 2021, representing 26.6% of the total yield. When evaluated on a treatment basis, the highest small tuber yields and proportions were generally observed in T4 (V) and T8 (C \times P), where marketable and large tuber yields were comparatively lower. In these treatments, small tuber yields were 3.7 and 2.9 t ha⁻¹, accounting for 16.9% and 17.7% of the total yield, respectively. In contrast, among the multiple organic fertilizer combinations, T15 (S \times V \times P) and T16 (C \times S \times V \times P) produced lower yields of small tubers, ranging between 2.1 and 2.2 t ha⁻¹, with corresponding proportions of 10.1% and 8.68% of the total tuber yield (Table 2, Figure 2).

Table 2. Effects of different organic fertilizers and their combinations on marketable (>3.8 cm), large (>5.0 cm), medium (3.5-5.0 cm), small (2.8-3.5 cm), cull tuber yields (<2.8 cm), and the percentage distribution of tuber size classes within total tuber yield of potatoes

Treatments	Marketable tuber yield (>3.8 cm)		Large tuber yield (>5.0 cm)		Medium tuber yield (3.5-5.0 cm)		Small tuber yield (2.8-3.5 cm)		Cull tuber yield (<2.8 cm)	
	t ha ⁻¹	%	t ha ⁻¹	%	t ha ⁻¹	%	t ha ⁻¹	%	t ha ⁻¹	%
<i>Year</i>										
2020	24.9 a	92.3	18.5 a	68.6	6.4 b	23.8	1.3 b	4.7	0.6 b	2.2
2021	11.1 b	66.5	2.9 b	17.4	8.2 a	49.1	4.2 a	26.6	1.7 a	9.9
<i>Organic fertilizers and treatment combinations</i>										
T ₁ (Control)	13.9 bc	78.3	8.4 ab	47.2	5.5 b	31.0	2.6 ab	14.8	1.2	6.9
T ₂ (Cattle, C)	18.3 ac	85.3	10.2 ab	47.4	8.1 ab	37.9	2.6 ab	12.0	1.2	5.7
T ₃ (Sheep, S)	17.5 ac	81.1	9.4 ab	43.4	8.1 ab	37.1	3.0 ab	13.9	1.1	5.3
T ₄ (Vermicompost, V)	17.2 ac	79.9	8.8 ab	41.1	8.4 ab	39.1	3.7 a	16.9	1.2	5.5
T ₅ (Poultry, P)	20.0 ac	84.4	12.6 ab	53.2	7.4 ab	31.1	3.0 ab	12.8	1.2	4.9
T ₆ (C×S)	17.5 ac	83.9	11.2 ab	54.2	6.2 b	29.9	2.5 ab	11.9	1.4	6.5
T ₇ (C×V)	18.1 ac	80.6	10.1 ab	44.9	8.0 ab	35.5	2.9 ab	13.3	1.2	6.3
T ₈ (C×P)	12.8 c	76.3	7.0 b	41.5	5.8 b	34.5	2.9 ab	17.7	1.1	6.3
T ₉ (S×V)	17.4 ac	75.7	10.2 ab	44.5	7.2 ab	31.3	2.8 ab	12.3	1.1	4.7
T ₁₀ (S×P)	19.0 ac	82.7	11.3 ab	48.7	7.8 ab	33.4	2.9 ab	12.9	1.1	4.7
T ₁₁ (V×P)	20.5 ab	82.1	10.9 ab	43.6	9.6 a	38.6	3.3 ab	13.1	1.2	4.7
T ₁₂ (C×S×V)	19.9 ac	84.5	11.9 ab	50.4	8.0 ab	33.9	2.7 ab	11.6	0.9	3.9
T ₁₃ (C×S×P)	20.1 ac	85.4	14.3 a	60.7	5.8 b	24.8	2.6 ab	10.9	1.3	5.4
T ₁₄ (C×V×P)	17.4 ac	83.7	11.3 ab	54.3	6.1 b	29.5	2.5 ab	12.2	0.9	4.1
T ₁₅ (S×V×P)	17.2 ac	84.8	10.5 ab	51.9	6.7 ab	33.0	2.1 b	10.1	1.0	5.0
T ₁₆ (C×S×V×P)	22.0 a	87.9	13.5 a	53.9	8.5 ab	33.8	2.2 b	8.68	0.9	3.6
<i>Mean</i>	18.1	82.3	10.7	48.8	7.3	32.8	2.8	12.8	1.2	5.3
<i>Variation sources</i>	<i>df</i>									
Y	1	**	**	**	**	**	**	**	**	**
T	15	*	*	*	*	*	*	*	*	ns
Y×T	15	ns	ns	ns	ns	ns	ns	ns	ns	ns
Error	62									

Statistically significant at 5% ($p<0.05$)* and 1% ($p<0.01$)**; ns: nonsignificant. Values followed by the same letter are insignificant.

Cull tuber yield increased markedly between years; the values recorded in 2020 (0.6 t ha⁻¹, accounting for 2.2% of the total tuber yield) rose to 1.7 t ha⁻¹ in 2021, representing 9.9% of the total yield. When evaluated in terms of organic fertilizer treatments, the lowest cull tuber yields and proportions were observed in T12 (C×S×V), T14 (C×V×P), and T16 (C×S×V×P). In these treatments, the cull tuber yield was 0.9 t ha⁻¹, with proportions ranging from 3.9% to 4.1% of the total yield. In contrast, the proportion of cull tuber was found to be higher in the T6 (C×S) and T1 (Control) treatments (Table 2, Figure 2).

4. Discussion

The variations observed in marketable and different tuber size yields between years can be largely attributed to the adverse ecological conditions prevailing during the second experimental year. In the first year, more favorable temperature and moisture conditions during the tuber growth and development likely enhanced the mineralization of nutrients derived from organic fertilizers, resulting in higher proportions of marketable

and large-sized tubers. Conversely, high temperatures and low humidity in June and July of the second year likely increased respiratory losses, thereby limiting tuber bulking and reducing the proportions of marketable and large tubers. Under these stress conditions, limited translocation of photosynthates to the tubers may have contributed to the increased proportions of small and cull tubers. Furthermore, the reduced mineralization rate of nutrients from organic sources under hot and dry conditions may have delayed nutrient availability and uptake, thereby adversely affecting tuber size distribution. Although rainfall increased and temperatures declined in August, these changes were insufficient to adequately stimulate mineralization processes (Figure 1). Overall, these findings indicate that the effectiveness of organic fertilizer applications on marketable tuber yield is strongly dependent on climatic conditions. Similarly, previous studies have reported that climatic factors may exert a more decisive influence on potato yield and tuber size distribution than fertilizer type (Honeycutt, 1997; Warman & Havard, 1998; Kjellenberg & Granstedt, 1998).

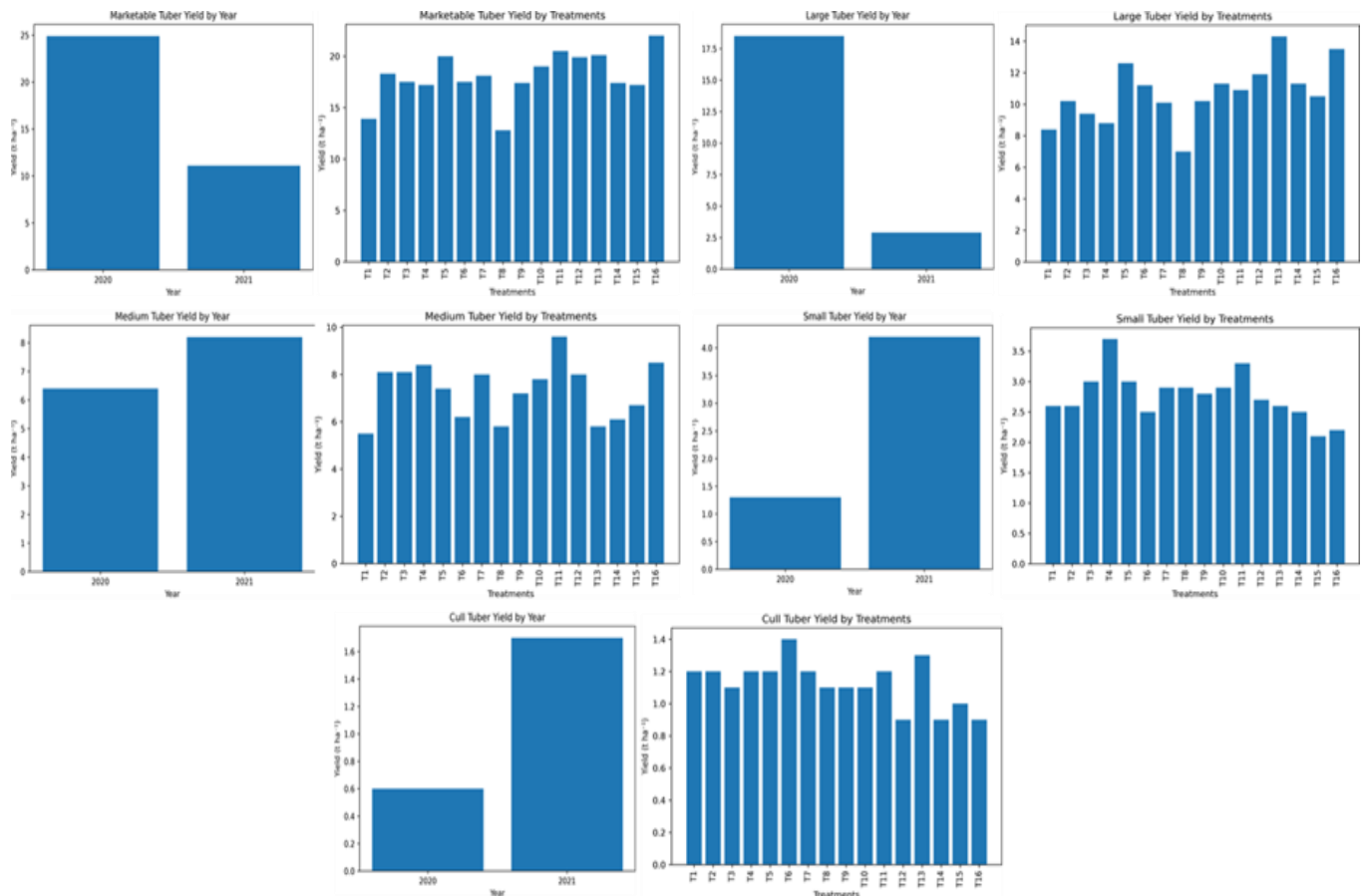


Figure 2. Effects of year and organic fertilizer treatments on marketable (>3.8 cm), large (>5.0 cm), medium (3.5-5.0 cm), small (2.8-3.5 cm), and cull (<2.8 cm) tuber yield

The growth and tuber quality enhanced by organic fertilizer applications are associated with increases in soil organic matter content, cation exchange capacity (CEC), and mineral nutrient levels. Furthermore, these fertilizers contribute to meeting crop requirements and supporting production by increasing the availability of macro and micro nutrients in the soil (Mirdad, 2010). These findings are consistent with the results of Shahein et al. (2014), Amara et al. (2015), and Bilkis et al. (2018), who reported that organic fertilizer applications significantly improve yield and crop characteristics in potato as well as other crops such as eggplant, cowpea, and watermelon. Numerous studies have demonstrated that, compared to the application of chemical fertilizers alone, the use of organic fertilizers can significantly improve soil quality, thereby playing a crucial role in enhancing crop yields (Zhou et al., 2022; Liu et al., 2023). It is widely recognized that fertilizers such as manure and straw provide a more comprehensive nutrient profile and a greater overall input of organic matter than commercial organic fertilizers, thereby ensuring a more adequate and sustained nutrient supply for optimal potato growth (Lin et al., 2023; Qiao et al., 2024).

The results of the study indicated that, rather than the sole application of individual fertilizers, the application of recommended doses in specific combinations generally produced better results in obtaining tubers of different sizes (Table 2). On the other hand, the application of 100% of the same nutrient source alone was not found to be highly effective in producing tubers of varying sizes. This situation may be attributed to nutrient losses under single-fertilizer use, resulting in insufficient nutrient availability during the tuber growth period (Keisham et al., 2015). It has been reported that the application of recommended fertilizer doses in combination increases the production of tubers of different sizes (Kumar et al., 2008; Das et al., 2009).

The increased quantity of marketable and large tubers through co-application of organic fertilizers is thought to result from improved soil friability, which creates a more conducive environment for tuber expansion. Furthermore, the likely reason for the increase in marketable yield is the enhanced availability of soil nutrients for vegetative growth, subsequently leading to higher production of photosynthates (photo assimilates). It has been demonstrated that organic fertilizer treatments lead to a significant increase in marketable yield compared to the control (Kahlel,

2014). Al-Sahaf and Atee (2007) reported that organic compounds and amino acids formed during the decomposition of organic fertilizers promote vegetative growth, positively reflecting on total and marketable yields. These results align with findings reported by Mohamed et al. (1999), Al-Zahawi (2007), Al-Zubi et al. (2007), Abdul-Rasol et al. (2009) and Al-Qaesi (2009). Ahmed et al. (2019) also noted that organic fertilizer types influence the formation of different tuber sizes and increase large tuber yield. Similar studies have reported significant differences between different cultivars (Bhardwaj et al., 2008) and treatments (Banjare et al., 2014; Chilephake & Trautz, 2014) regarding tuber yields of different sizes. In addition, the combined application of specific organic fertilizer doses reduced small tuber yield. This effect may be explained by the more balanced and growth-promoting nutrient supply provided through combined applications (Grappelli et al., 1985; Tomati et al., 1990). Indeed, the combined use of organic fertilizers has been reported to enhance soil nutrient availability and biological activity (Pengthamkeerati et al., 2011). As a consequence of improved plant growth, tuber volume increased, leading to a proportional reduction in the proportion of small tubers.

In this study, marketable tuber yield and size distribution were significantly influenced by organic fertilizer type, application method, and inter-annual climatic variations. Favorable climate conditions in the first year enhanced the mineralization of nutrients, increasing marketable and large tuber ratios. However, high temperatures and low humidity in the second year restricted tuber bulking, resulting in higher proportions of small and cull tubers.

5. Conclusion

Overall, the results clearly indicate that increasing the number of organic fertilizers applied in combination improved not only total yield but also the proportion of marketable and large tubers, while reducing the proportions of small and cull tubers. The results indicated that fertilizer treatments significantly affected total yield, marketable yield, and tuber size distribution in both years. Generally, combined applications outperformed individual applications. Specifically, the highest marketable tuber yield (22.0 t ha⁻¹) and marketable tuber proportion (87.9%) were obtained from the T16 treatment. While the highest large tuber yields were recorded in T13 (14.3 t ha⁻¹) and T16 (13.5 t ha⁻¹) treatments, the maximum medium and small tuber yields were found in T11 (9.6 t ha⁻¹) and T4 (3.7 t ha⁻¹) treatments, respectively. The positive response of potato to the combined application of organic fertilizers may be attributed to their different solubility and

mineralization rates, which enable a gradual and balanced supply of nutrients throughout the growing period. The application of cattle, sheep, vermicompost, and poultry manures at 25% each of their recommended doses (T16 - C×S×V×P) provided the highest marketable yield and the most balanced size distribution compared to individual applications. These findings suggest that in high-altitude ecological conditions, the complementary use of diverse organic fertilizers with different characteristics instead of a single fertilizer source is a sustainable and effective method for both yield and market quality.

Acknowledgement

This study was supported by Atatürk University Scientific Research Projects Coordination Unit (Project No: FDK- 2020-8496).

Conflict of interest

The authors declare no conflict of interest.

Ethical Approval

This article does not require ethics committee approval.

References

- Abdul-Rasol, K. J., Jawad, K. S., & Al-Dolayme, H. Y. (2009). Effect of organic and mineral fertilizer in the growth and yield of potatoes and concentration of NPK nutrients in the leaves of the plant in different stages of growth. *Iraqi Journal of Agricultural Sciences*, 40(1), 56-68.
- Ahmad, S., Ullah, B., Ali, S., Zaid, A., Ahmad, Z., Usaid, M., Zeeshan, M., & Ullah, S. (2023). Impact of nitrogen and organic sources with and without beneficial microbes on wheat crop. *Sarhad Journal of Agriculture*, 39(4), 876-882. <https://dx.doi.org/10.17582/journal.sja/2023/39.4.876.882>
- Ahmed, F., Mondal, M. M. A., & Akter, M. B. (2019). Organic fertilizers effect on potato (*Solanum tuberosum* L.) tuber production in sandy loam soil. *International Journal of Plant and Soil Science*, 29(3), 1-11.
- Al-Qaesi, M. R. (2009). Effect of magnetic irrigation water, chemical fertilizer and types of natural organic fertilizers on growth and yield of water

- melon growth in gypsum soils. *Diyala Agricultural Sciences Journal*, 1(2), 124-133.
- Al-Sahaf, F. H., & Atee, A. S. (2007). Potato productivity by organic farming: 3-Effect of organic fertilizer and whey on plant growth, yield and tubers quality characteristics. *Iraqi Journal of Agricultural Sciences*, 38(4), 65-82.
- Al-Zahawi, S. M. A. (2007). *Effect of the using of organic fertilizers and soil cover in the growth, production and quality of potatoes* [Master's thesis, University of Baghdad].
- Al-Zubi, M. M., Haissam, E., & Mohammed, E. (2007). Effect of organic and bio-fertilizer on production of potatoes and some soil properties in Tartous. *Damascus University Journal for Agricultural Sciences*, 23(2), 151-162.
- Amara, D. G., Kherraz, K., Nagaz, K., & Senoussi, M. M. (2015). Effect of chicken manure and organic nitrogen levels on yielding and antioxidant content of tuber potato at Algeria Sahara. *International Journal of Agriculture Innovations and Research*, 4(1), 17-21.
- Banjare, S., Sharma, G., & Verma, S. K. (2014). Potato crop growth and yield response to different levels of nitrogen under Chhattisgarh plains agro-climatic zone. *Indian Journal of Science and Technology*, 7(10), 1504-1508.
- Bhardwaj, V., Pandey, S. K., Manivel, P., Singh, S. V. & Kumar, D. (2008). *Stability of indigenous and exotic potato processing cultivars in Himachal Pradesh hills* [Oral presentation]. Global Potato Conference, New Delhi, India.
- Bilkis, S., Islam, M. R., Jahiruddin, M., Rahman, M. M., & Hoque, T. S. (2018). Residual effects of different manures and fertilizers applied to preceding potato crop on succeeding mung bean (*Vigna radiate* L.) crop in potato-mung bean-rice cropping pattern. *SAARC Journal of Agriculture*, 16(2), 167-179. <https://doi.org/10.3329/sja.v16i2.40268>
- Blecharczyk, A., Kowalczewski, P. Ł., Sawinska, Z., Rybacki, P., & Radzikowska-Kujawska, D. (2023). Impact of crop sequence and fertilization on potato yield in a long-term study. *Plants*, 12(3), 495. <https://doi.org/10.3390/plants12030495>
- Chilephake, U., & Trautz, D. (2014). *Tuber development rates of six potato varieties in organic farming in Osnabrück, Germany* [Oral presentation]. 4th ISOFAR Scientific Conference: 'Building Organic Bridges', Istanbul, Türkiye.
- Das, P. P., Sarkar, A., & Zamen, A. (2009). *Response of organic and inorganic sources of nutrients on growth and yield of potato in Gangetic alluvial plains of west Bengal* [Oral presentation]. 96th Indian Science Congress, Shillong, India.
- Devaux, A., Kromann, P., & Ortiz, O. (2014). Potatoes for sustainable global food security. *Potato Research*, 57(3), 185-199. <https://doi.org/10.1007/s11540-014-9265-1>
- Edwards, C. A., & Arancon, N. Q. (2022). The Use of Earthworms in Organic Waste Management and Vermiculture. In C. A. Edwards, & N. Q. Arancon (Eds.), *Biology and Ecology of Earthworms* (pp. 467-527). Springer.
- El-Sayed, S. F., Hassan, H. A., El-Mogy, M. M., & Abdel-Wahab, A. (2014). Growth, yield and nutrient concentration of potato plants grown under organic and conventional fertilizer systems. *American-Eurasian Journal of Agricultural & Environmental Sciences*, 14(7), 636-643. <https://doi.org/10.5829/idosi.ajeaes.2014.14.07.12361>
- FAO. (2022). Statistical Database-Agriculture. <http://www.fao.org>
- Gayathri, A., Vadivel, A., Santhi, R., Boopathi, P. M., & Natesan, R. (2009). Soil test based fertilizer recommendation under integrated plant nutrition system for potato (*Solanum tuberosum* L.) in hilly tracts of Nilgiris district. *Indian Journal of Agricultural Research*, 43(1), 52-56.
- Hargreaves, J. C., Adl, M. S., & Warman, P. R. (2008). A review of the use of composted municipal solid waste in agriculture. *Agriculture, Ecosystems & Environment*, 123, 1-14. <https://doi.org/10.1016/j.agee.2007.07.004>
- Honeycutt, C. W. (1997). Quantifying total, N and non-N related crop rotation effects without ¹⁵N. *Biological Agriculture & Horticulture*, 14(2), 125-137. <https://doi.org/10.1080/01448765.1997.9754802>
- Hussain, I., Hussain, I., F-i-Wahid, G. Gul, Shah, W. U., Numan, M., & Anas, M. (2024). Effect of organic fertilizers on potato cultivars in Parachinar (District Kurram), Pakistan. *Sarhad Journal of Agriculture*, 40(3), 1018-1026. <https://dx.doi.org/10.17582/journal.sja/2024/40.3.1018.1026>
- Ingallina, C., Spano, M., Sobolev, A. P., Esposito, C., Santarcangelo, C., Baldi, A., Daglia, M., & Mannina, L. (2020). Characterization of local products for their industrial use: The case of Italian potato cultivars

- analyzed by untargeted and targeted methodologies. *Foods*, 9, 1216. <https://doi.org/10.3390/foods9091216>
- Kahlel, A. S. (2014). Effect of organic fertilizer and dry bread yeast on growth and yield of potato (*Solanum tuberosum* L.). *Turkish Journal of Agricultural and Natural Sciences*, 2, 1977-1984.
- Kjellenberg, L., & Granstedt, A. (1998). Samband mellan mark, grdda och gddsling. The Biodynamic Research Institute Report I; Jama, Sweden.
- Kmet'ová, M., Kováčik, P., & Renčo, M. (2013). The effect of different doses application of dry granulated vermicompost on yield parameters of maize and potatoes. *Acta Fytotechnica et Zootechnica*, 16(1), 8-14.
- Kumar, M., Jadav, M. K., & Trehan, S. P. (2008). *Contributing of organic sources to potato nutrition at varying nitrogen levels* [Oral presentation]. Global Potato Conference, New Delhi, India.
- Leytem, A. B., & Westermann, D. T. (2005). Phosphorus availability to barley from manures and fertilizers on a calcareous soil. *Soil Science*, 170(6), 401-412. <https://doi.org/10.1097/01.ss.0000169914.17732.69>
- Lin., X. T., Xu, S., H., Liu, H., (2023). Effects of different decomposed straw fertilizer on tobacco-growing soil and tobacco quality. *Guizhou Agricultural Sciences*, 51(6), 48-58.
- Liu, W., Cui, S., Wu, L., Qi, W., Chen, J., Ye, Z., Ma J. & Liu, D. (2023). Effects of bio-organic fertilizer on soil fertility, yield, and quality of tea. *Journal of Soil Science and Plant Nutrition*, 23(4), 5109-5121. <https://doi.org/10.1007/s42729-023-01195-6>
- Mirdad, Z. M. (2010). The effect of organic and inorganic fertilizers application on vegetative growth, yield and its components and chemical composition of two potato (*Solanum tuberosum*, L.) cultivars. *Alexandria Science Exchange Journal*, 31(1), 102-119.
- Mohamed, F. I., Hallal, F. A., & El-Shabraway, R. A. (1999). A comparative study on the effect of bread yeast and folige nutrients application on the productivity and quality of two pea cultivars. *Egyptian Journal of Applied Science*, 14(10), 284-299.
- Perez, D. V., Alcantara, S., Ribeiro, C. C., Pereira, R. E., Fontes, G. C., Wasserman, M. A., Venezuela, T. C., Meneguelli, N. A., de Macedo, J. R. C., & Barradas, A. A. (2007). Composted municipal waste effects on chemical properties of a Brazilian soil. *Bioresource Technology*, 98(3), 525-533. <https://doi.org/10.1016/j.biortech.2006.02.025>
- Pengthamkeerati, P., Motavallib, P. P., & Kremerc, R. J. (2011). Soil microbial activity and functional diversity changed by compaction: poultry litter and cropping in a claypan soil. *Applied Soil Ecology*, 48(1), 71-80.
- Qiao, Q. L., Wu, Y. R., Li, Q. Y., Zhang, Y. C., Kou, W. L., He, X. T., Li, X. L., Kou, J. C., & Yang, W. Q. (2024). The effects of commercial organic fertilizer and semi decomposed sheep manure on artificial grassland and soil characteristics in alpine mining area. *Acta Agrestia Sinica*, 32(8), 2659-2669.
- Seaman, A. (2015). *Production guide for organic potatoes*. New York State Integrated Pest Management Program, Cornell University.
- Sezen, Y. (1991). Fertilizers and fertilization lecture notes. Atatürk University, Faculty of Agriculture, Department of Soil Science, Erzurum. (in Turkish)
- Shahein, M. M., Husein, M. E., Ahmed, A. R., & Shaker, N. A. (2014). Effect of integrated inorganic and organic nitrogen fertilizer on quantity and quality of potatoes plant grown on new reclaimed sandy soil. *Journal of Soil Sciences and Agricultural Engineering*, 5(11), 1451-1472.
- Şanlı, A., Karadoğan, T., & Tonguç, M. (2013). Effects of leonardite applications on yield and some quality parameters of potatoes (*Solanum tuberosum* L.). *Turkish Journal of Field Crops*, 18(1), 20-26.
- Tomati, U., Galli, E., Grappelli, A., & Di Lena, G. (1990). Effect of earthworm casts on protein synthesis in radish (*Raphanus sativum*) and Lettuce (*Lactuca sativa*) Seedlings. *Biology and Fertility of Soils*, 9(4), 288-289.
- Vilvert, E., Stridh, L., Andersson, B., Olson, Å., Aldén, L., & Berlin, A. (2022). Evidence-based disease control methods in potato production: a systematic map protocol. *Environmental Evidence*, 11(1), 6. <https://doi.org/10.1186/s13750-022-00259-x>
- Walia, S., Kaur, T., Gupta, R., Siddiqui, H. M. & Rahman, M. A. (2023). Long-term impact of the continuous use of organic manures on crop and soil productivity under maiz-potato-onion cropping systems. *Sustainability*, 15(10), 8254. <https://doi.org/10.3390/su15108254>
- Warman, P. R., & Havard, K. A. (1998). Yield, vitamin and mineral contents of organically and conventionally grown potatoes and sweet corn. *Agriculture, Ecosystems & Environment*, 68(3), 207-216. [https://doi.org/10.1016/S0167-8809\(97\)00102-3](https://doi.org/10.1016/S0167-8809(97)00102-3)

- Yourtchi, M. S., Hadi, M. H. S., & Darzi, M. T. (2013). Effect of nitrogen fertilizer and vermicompost on vegetative growth, yield and NPK uptake by tuber of potato (Agria CV.). *International Journal of Agriculture and Crop Sciences*, 5(18), 2033-2040.
- Zandian, F., Mollae, M., & Shirzadi, F. (2015). Evaluate the use of organic fertilizers on the plant's height and size and number of micro tubers potato in Mahidasht of Kermanshah. *International Journal of Research Studies in Agricultural Sciences*, 1(4), 21-24.
- Zhou, Z., Zhang, S., Jiang, N., Xiu, W., Zhao, J. & Yang, D. (2022). Effects of organic fertilizer incorporation practices on crops yield, soil quality, and soil fauna feeding activity in the wheat-maize rotation system. *Frontiers in Environmental Science*, 10, 1058071.
<https://doi.org/10.3389/fenvs.2022.1058071>