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The Effects of Agricultural Drone Use on Agricultural Production, Yield and Profitability: The Case of Samsun Province

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Abstract: It is necessary to switch to digital farming practices to increase the efficiency in agricultural production and to meet the increasing population's food needs. Digital agricultural practices provide significant advantages to farmers at many stages of production. This study analysed the effects of agricultural drone use, a digital farming practice, on farmers' production, yield, and income in paddy production in Samsun province. The results of the study showed that the use of agricultural drones increased gross profit by 107.31% and net profit by 254.61%. In addition, the increase in relative profit from 1.20% to 1.73% revealed that drones increased farmers' competitiveness in some aspects such as homogenous planting, optimum fertilization, and spraying. Although it is not possible to say that all of the increased profit is due to the use of drones, it can be said that this change is largely due to the use of drones. It should be kept in mind that similar analyses should be repeated to fully understand the effects of agricultural drones and that comprehensive training programs and legal regulations should be reviewed for the effective use of this technology.

Keywords: Agricultural drone, digital farming practices, production costs, productivity, profitability.

Zirai Dron Kullanımının Tarımsal Üretim, Verim ve Karlılık Üzerine Etkileri: Samsun İli Örneği

Öz: Artan nüfusun gıda ihtiyacını karşılamak amacıyla tarımsal üretimde verimi artırmak için, dijital tarım uygulamalarına geçiş gerekliliği ortaya çıkmaktadır. Dijital tarım uygulamaları üretimin pek çok aşamasında çiftçilere önemli avantajlar sağlamaktadır. Bu çalışmada, Samsun ilinde çeltik üretiminde, dijital tarım uygulamalarından olan zirai dron kullanımının çiftçilerin üretim, verim ve gelirleri üzerindeki etkileri incelenmiştir. Araştırma sonuçları, zirai dron kullanımının brüt karı %107.31, net karı %254.61 artırdığını göstermiştir. Ayrıca, nispi karın %1.20'den %1.73'e yükselmesi, dronların sağladığı homojen ekim, optimum gübreleme ve ilaçlama gibi avantajlarla çiftçilerin rekabet gücünü artırdığını ortaya koymuştur. Her ne kadar artan karın tamamının dron kullanımından kaynaklandığını söylemek mümkün olmasa da bu değişimin büyük oranda dron kullanımına bağlı olduğu söylenebilir. Zirai dronların etkilerini tam olarak anlamak için benzer analizlerin tekrarlanması gerektiği ve bu teknolojinin etkin kullanımı için kapsamlı eğitim programları ile yasal düzenlemelerin gözden geçirilmesi gerektiği unutulmamalıdır.

Anahtar Kelimeler: Dijital tarım uygulamaları, karlılık, üretim maliyetleri, verimlilik, zirai dron.

1. Introduction

Due to the rapid increase in world population, great challenges occur in meeting food demand. According to United Nations data, the world population is expected to reach approximately 10 billion people by 2050 (Anonymous, 2023). This situation questions the adequacy of current agricultural production methods and shows that food production should be increased by about 50 percent (Hafeez et al., 2023). The agricultural sector plays a critical role in ensuring food security, which is one of the basic needs of humanity. However, increasing population and urbanization lead to a decrease in agricultural areas and natural resources (Özgüven et al., 2021). Under these conditions, increasing productivity in agricultural production is of great importance. While the farming sector faces many challenges such as climate change, environmental degradation, and price fluctuations, the spread of modern technologies in agriculture offers opportunities to overcome these challenges (Pakdemirli et al., 2021).

To increase productivity, factors such as the use of chemical inputs, mechanization, development of irrigation facilities, and expansion of arable areas should be taken into consideration (Hazneci & Arslanoğlu, 2021; Keleş et al., 2023). At this point, innovative applications in digital agricultural technologies have also started to play an important role in agricultural production. In accordance with the EU aims to be climate-neutral 2050, the European Union announced the European Green Deal, which encourages the use of

digital technologies in agriculture. In line with these targets, Turkey aims to invest in environmentally friendly technologies and reduce dependence on resource use with the 'Green Deal Action Plan' (Ercan et al., 2019).

Digital agriculture refers to the tools that collect data in a digital environment store, analyse, and transfer this data to the end user (Anonymous, 2021). Data are collected in new-generation technologies such as sensors and drones (Öztekin et al., 2023). Thanks to digital agriculture, it is possible to obtain real information about the planting and harvesting time, meteorological forecasts, soil quality, the number of workers required, and costs in advance (Anonymous, 2021).

In recent years, unmanned aerial vehicles (UAVs) have been adopted by various sectors by facilitating costly and labour-intensive processes (Macit, 2023). The agriculture sector is one of them (Türkseven et al., 2016). Agricultural drone technology, one of the UAVs, contributes to agricultural research and applications by using remote sensing and data analytics. These technologies, which help to improve the working and living standards of farmers in agriculture, are supported by software and hardware developments in Turkey (Yangal et al., 2022). Agricultural drones are mostly used for crop monitoring, sowing and planting, weed control, insect control, plant health, plant analysis, weather forecasts, and yield monitoring (URL 1, 2023).

There are studies on digital farming technologies and the use of agricultural drones in the world. (Alimuzzaman, 2015; Deepak, 2018; Ghazali et al., 2022; Hafeez et al., 2023; Kushvaha et al., 2021; Mhetre et al., 2020; Mogili & Meetali et al., 2020; Puri et al., 2017; Shahrooz et al., 2020; Sharma et al., 2021). When the studies on digital agriculture applications in Turkey to date are examined, digital agriculture (Aldağ et al., 2018; Dayıoğlu et al., 2020; Kılavuz & Erdem, 2019; Kirmikil & Ertaş, 2020; Pakdemirli et al., 2021; Şahin, 2022; Tutkunca & Haydar, 2022; Varnalı, 2024), smart agriculture applications (Çokuysal, 2021; Ercan et al, 2019; Kaya, 2019; Yılmazer & Tunalıoğlu, 2024), agriculture 4.0 (Aday & Aday, 2020; Gökkur, 2019; Yıldız, 2021; Yüksel, 2020), agricultural drone technology (Kaya & Goraj, 2020; Macit, 2023; Özgüven et al., 2021; Türkseven et al., 2016; Ünal, 2024), but no studies focusing on the effects of digital applications in agriculture on agricultural production process and yield. were found. The research aims to reveal the technical and economic effects of agricultural drone use on enterprises, which is one of the digital agriculture applications. In the study, the effects of agricultural drone use on production, yield, costs, profitability, and the willingness of producers to continue the use of agricultural drones were examined. In this respect, the study aimed to reveal with numerical analyses whether the use of drones has positive effects on yield and profitability as mentioned in the literature.

2. Material and Method

2.1. Material

The main material of the research was the data obtained from the questionnaires conducted with the producers using agricultural drones in Bafra and Çarşamba districts of Samsun province. The questionnaires included questions on socio-demographic information, structural and economic characteristics, agricultural drone use, and problems encountered. In addition, data from the Ministry of Agriculture and Forestry and information obtained from observations in the field were also included in the study. In addition, previous domestic and foreign studies on the subject were also utilized.

2.2. Method

2.2.1. The method applied in data collection

Only the Bafra and Çarşamba districts constitute 31.33 percent of the total agricultural lands in 17 districts in Samsun. At the same time, the intensity of agricultural drone use was determined in these two districts. Therefore, Bafra and Çarşamba districts were selected for the study. In the research, according to the complete census method, all enterprises using agricultural drones in Bafra and Çarşamba districts were interviewed. In the region, 27 paddy producers who rented agricultural drones from Helimore Aviation, R&D, Design, Engineering, Technology Manufacturing Industry Limited Company, which was established in cooperation with Ondokuz Mayıs University Technopark in 2019, were interviewed. In addition, 10 paddy producers who rented drones from Tekno Tarım Aviation Company, which just started drone rental activities in 2023, and 23 producers who rented drones from Sonagtech Sönmez Agricultural Technologies Company were interviewed. Research data were obtained from face-to-face interviews with a total of 60 producers. The surveyed producers have been producing paddy for many years. However, most of the producers have rented drones to carry out their agricultural activities between the last 1 and 3 years. The location of. the research area is shown in Figure 1 (Özçelebi & Yılmaz, 2020).

Figure 1. Location of the research area
Şekil 1. *Araştırma alanının konumu*

2.2.2. The method applied in the analysis of the data

In the summer of 2023, the enterprises utilizing agricultural drone application was visited with the officials of the company renting drones and these processes were monitored in the field by the researchers. With the surveys conducted with farmers before and after the application, both the input-output coefficients of the production activity and the effects of agricultural drone application on the production processes and yields of farmers were determined. Within this direction, the possible effects of agricultural drone use on farmer incomes were determined by comparing the production carried out with traditional methods and that carried out using agricultural.

As a result of the surveys and observations made in the field, it was observed that agricultural drones are intensively used in paddy production activities in the research region. All of the producers who rent agricultural drones in the region rent drones to use in paddy production. For this reason, firstly, the amount of inputs used in production and the outputs obtained as a result of the use of agricultural drones in paddy production activities were determined. If the same production activity is carried out with traditional methods, the inputs used and the outputs obtained are compared and the effect of drone use on input and output coefficients is revealed. After determining the input and output coefficients, calculations were made based on the market prices of variable inputs. Differences between the use of agricultural drones and traditional methods were examined and their effects on yield and costs were analysed. In addition, the economic impact of drone use was evaluated by calculating the gross, net, and relative profits of the activities.

Production costs are divided into two fixed and variable costs. While fixed costs include costs that do not depend on the amount of production, variable costs vary depending on the amount of production (Erkuş & Demirci, 1985). Variable costs were calculated one by one in the production carried out with the use of agricultural drones and compared with the production carried out with traditional methods. Variable costs included elements such as soil preparation, sowing, spraying, fertilization, seed, fuel oil, irrigation, labour, harvesting, transportation, and marketing. Within the scope of the study, the revolving fund interest, which is included in variable costs, was calculated at half of the interest rate (16.15%) determined by the Türkiye Ziraat Bankası for crop production loans. Fixed costs consist of general administrative expenses and land rent. Administrative expenses were calculated as 3% of variable expenses, and land rent was determined according to the declarations of the producers.

As a result of the study, it was determined that the use of agricultural drones only made a difference in planting, fertilizing, and spraying processes in paddy production. Other production stages (soil preparation, seed, irrigation, harvesting, drying, transportation) were carried out in the same way in both production using drones and traditional production. Therefore, the coefficients for traditional paddy production were determined and costs were calculated by multiplying them with 2023 market prices. Planting, fertilizing, and spraying activities resulting from the use of drones were calculated and analysed with new coefficients.

A profitability analysis was performed to calculate the economic return of agricultural drone use to enterprises, and gross profit, net profit, and relative (proportional) profit were calculated with the help of the equations given below. Gross Production Value (GPV) was obtained by multiplying the product price by the yield values per decare (Açıl & Demirci, 1984; Cinemre, 2013; Hazneci & Arslanoğlu, 2021; Hazneci et al., 2022; Kıral et al., 1999; Tanrıvermiş, 2000). All producers in the research region benefit from fuel and fertilizer support. Fuel-fertilizer support was determined as 271 TL per decare (Anonymous, 2023a) and was added to GVV while conducting the analysis.

Gross profit = GPV - Variable Costs

Net profit = GPV - Total Production Costs

Relative profit = GPV / Total Production Costs

In addition, the reasons for starting and continuing production with agricultural drones, the problems encountered, and the opinions of the producers on the use of agricultural drones were also revealed in the research.

3. Results and discussion

All of the producers interviewed in the study were male. The age of the producers varied between 30 and 72 and the average age was calculated as 55.13. The years of education of the producers varied between 5 and 16, and it was determined that the average education of the producers was 8.81 years. The average agricultural land size of the analysed farms is 24.5 hectares. It was observed that the smallest land size was 80 ha and the largest land size was 600 ha among the enterprises analysed in the research region. 43 business managers who participated in the research are only engaged in agriculture. While 6 people work as civil servants along with agriculture, 11 people work as tradesmen along with agriculture. It was determined that all of the enterprise managers in the research region have social security. 57% of the producers are covered by BAĞ-KUR, 32% by SGK, and 11% by Retirement Fund (Table 1)

Within the scope of the research, the effects of the use of agricultural drones on the production process were personally observed in the field and determined by interviewing farmers one-on-one. It has been determined that the use of agricultural drones differs from traditional methods in sowing, fertilization, and agricultural control of paddy crops. In the sowing stage, traditional methods usually require the use of human or agricultural machinery. In these methods, seed placement and sowing depth control usually depend on certain standards. In contrast, agricultural drones used in the research area were observed to analyse the characteristics of the fields using sensitive sensors and data analytics and ensure that the seeds are placed at optimum depth and spacing. In this way, homogenous planting is achieved and waste of resources is prevented

Table 1. Socio-demographic characteristics of enterprises

Çizelge 1. *İşletmelerin sosyo-demografik özellikleri*

	Mean Frequence (N)	Standard Deviation / Percentage (%)
Age (years)	55.13	10.95
Education Period (years)	8.81	3.72
Land Size (ha)	24.53	12.89
Occupation		
Farmer	43	71.67
Civil Servant	6	10
Tradesman	11	18.33
Total	60	100
Social Security		
SGK	19	31.67
BAĞ-KUR	34	56.67
Retirement Fund	7	11.66
Total	60	100

In the process of fertilization, traditional methods are usually done with a fertilizer spreader. This method causes some areas to be over- or under-fertilised. This leads to both fertilizer wastage and negative effects on soil fertility. However, agricultural drones use sensitive sensors to determine plant needs in different parts of the field and perform point fertilization accordingly. Thus, it has been observed that fertilizer is used more effectively and environmental impacts are minimized.

Traditional methods in agricultural control are generally done by spraying with a pulveriser. This method causes the same amount of spraying of healthy areas and areas where plant pests are dense. For this reason, some areas are sprayed more than necessary or not sprayed enough. In contrast, agricultural drones use advanced sensors and imaging technology to precisely identify pest hotspots. By applying pesticides only to the areas where they are needed, they optimize chemical use, reduce costs, and minimize environmental impacts, resulting in more effective pest control. According to the research findings, it was determined that productivity in paddy production increased significantly as a result of agricultural drone application (Table 2). Although it is not possible to attribute the entire increase in yield to the use of agricultural drones, it can be said that it is largely due to these practices.

Table 2. Cost and profitability indicators of paddy production activities before and after the use of agricultural drones

Çizelge 2. *Zirai dron kullanımı öncesi ve sonrasında çeltik üretim faaliyetinin maliyet ve karlılık göstergeleri*

Cost and Profitability Measurements (TL/ha)*	Before Agricultural Drone Use			After Agricultural Drone Use		
	Amount	Ratio 1 (%)**	Ratio 2 (%)***	Amount	Ratio 1 (%)**	Ratio 2 (%)***
Deep plowing and labor	4202.26	5.64	4.13	4202.26	6.02	4.34
2nd plowing and labor	2826.92	3.80	2.78	2826.92	4.05	2.92
Rice levee and labour	1779.47	2.39	1.75	1779.47	2.55	1.84
Raking and labour	655.28	0.88	0.64	655.28	0.94	0.68
Sowing and labour	10796.67	14.50	10.62	9290.83	13.32	9.59
Harvesting and labour	5941.00	7.98	5.84	5941.00	8.52	6.13
Drying and labour	3114.89	4.18	3.06	3114.89	4.47	3.22
Transport and labour	894.88	1.20	0.88	894.88	1.28	0.92
Irrigation and labour	4182.00	5.62	4.11	4182.00	6.00	4.32
Fertilisation and labour	22188.07	29.79	21.82	21737.23	31.16	22.44
Agricultural pest control and labour	7535.00	10.12	7.41	5433.33	7.79	5.61
Revolving fund interest	10354.81	13.90	10.18	9699.38	13.90	10.01
Total variable costs	*74471.25*	*100.00*	*73.22*	*69757.47*	*100.00*	*72.03*
General administration expenses	2234.14	8.20	2.20	2092.72	7.72	2.16
Land lease	25000.00	91.80	24.58	25000.00	92.28	25.81
Total fixed costs	*27234.14*	*100.00*	*26.78*	*27092.72*	*100.00*	*27.97*
Total production costs	*101705.39*		*100.00*	*96850.19*		*100.00*
Yield (kg/da)	6926.70			8040.80		
Sale price	17.17			20.50		
Gross value of production	118931.44			164836.40		
Support income	2710.00			2710.00		
Gross profit	47170.19			97788.93		
Net profit	19936.05			70696.21		
Relative profit (%)	1.20			1.73		

*1$ = 28.06 TL (24.10.2023)
** Ratio 1: Rates in variable and fixed costs
*** Ratio 2: Rates in total production costs

The differences between traditional farming methods and the use of agricultural drones are significant only in sowing, fertilization, and pest control processes. It was determined that the costs did not change in other cost items. While the sowing cost was 10796.67 TL/ha before the use of agricultural drones, this cost decreased to 9290.83 TL/ha afterward. Fertilization cost decreased from 22188.07 TL/ha to 21737.23 TL/ha and agricultural pest control cost decreased from 7535 TL/ha to 5433.33 TL/ha. These cost reductions indicate a 6.3% decrease in total variable costs (Table 2).

An increase was observed in yield after the use of agricultural drones. While the yield was 692.67 kg/ha before the use of agricultural drones (Anonymous, 2023a; Anonymous, 2023b), this yield increased to 804.08 kg/ha after the use of drones. However, an increase was also observed in the sale price. According to the statements received from the producers who did not use agricultural drones, the average sales price was 17.17 TL/kg, while this price increased to 20.50 TL/kg after the use of agricultural drones. The reason for the increase in sales price is due to the increase in yield. Agricultural drones enable more effective monitoring and management of agricultural lands, enabling homogenous planting, optimum fertilization, and agricultural control. According to the statements received from farmers, these factors positively affected productivity and consequently sales prices by about 19% (Table 2).

According to the research, while the total production cost was 101705.39 TL/ha before the use of agricultural drones, it was determined that these costs decreased by approximately 5% to 96850.19 TL/ha after the use of agricultural drones. While the gross profit was 47170.19 TL/ha before the use of agricultural drones, it was observed that the gross profit increased by 107.31% to 97788.93 TL/ha after the use of agricultural drones. In a study conducted in Çanakkale province, it was stated that paddy producers earned a gross profit of 12724.40 TL/ha with the support income. (Semerci, 2021). Net profit increased by 254.61% from 19936.05 TL/ha to 70696.21 TL/ha. According to the results of the research, relative profit increased from 1.20 percent to 1.73 percent. Accordingly, while the farmer earns 1.20 TL for 1 TL invested in traditional paddy production, he earns 1.73 TL for 1 TL invested in paddy production using agricultural drones (Table 2) In a study conducted in a nearby geography (Sinop province), the

proportional profit of paddy production was found to be 1.56 (Yuzbasioglu & Abaci, 2023).

Forty-five percent of the paddy producers participating in the research have been using agricultural drones for 3 years. About 17% of the producers have been renting drones for 2 years, while 38% of the producers rented drones in the last production year (Table 3). The enterprises decided to use agricultural drones with the advice of their colleagues. It was determined that all of the enterprises were satisfied with the use of agricultural drones and wanted to continue using this technology. Even all of the enterprises want to buy agricultural drones.

Table 3. Duration of use of agricultural drones by enterprises
Çizelge 3. *İşletmelerin zirai dron kullanım süreleri*

Year	Frequency	%
1	23	38.33
2	10	16.67
3	27	45.00
Total	60	100

The advantages and disadvantages of agricultural drone use are shown in Table 4. The general opinion of the surveyed enterprise managers is that agricultural drone technology has an important potential in agricultural activities. According to the interviewed business managers, since the use of agricultural drones offers optimum planting, fertilization, and spraying in unit areas, the continuity of this technology is considered inevitable. It has been observed that agricultural drone applications provide a reduction in the use of inputs (seed, fertilizer, pesticide) and time-saving, although labour costs are higher than traditional agricultural practices. Due to the mentioned contributions to the production process, the use of agricultural drones has become attractive among enterprises. Although the enterprises do not encounter any difficulties while using agricultural drones, some limitations are noteworthy. In particular, it was observed that there are obstacles such as high customs duty and the lack of night flight permits for agricultural drones. It was concluded that the enterprises are interested in digital agriculture practices and expect support from the government in this regard. In general, the enterprises stated that with the help of agricultural drone technology, productivity in agricultural production increased, costs decreased and it will be used more widely in the agricultural sector in the future (Table 4).

Table 4. Advantages and disadvantages of agricultural drone
Çizelge 4. *Zirai dron kullanımının avantaj ve dezavantajları*

Advantages	Frequency	%	Disadvantages	Frequency	%
Offers yield mapping capability	24	40	High customs duty	28	47
Positive impact on occupational health and safety	33	55	Legal obstacles	50	83
Environmentally friendly application	35	58	Lack of night flight permits	60	100
Provides precise and homogenous sowing	60	100	Restrictions in adverse weather conditions	60	100
Provides optimum fertilization and spraying	60	100	High customs duty		
Reduces input costs	60	100			
Saves labour and time	60	100			
Increases agricultural yield	60	100			

4. Conclusion

As a result of the research, it was determined that the use of agricultural drones, which is one of the digital agriculture practices, contributed to the increase in yield and accordingly to the increase in agricultural income of the enterprises. In Turkey, agricultural drones are at the centre of digital farming practices and make significant contributions to agricultural production processes. As a result of the research, it was determined that these technologies increase agricultural productivity by making homogeneous and precise spraying in critical production stages such as sowing, fertilization, and spraying. In addition, the use of agricultural drones will contribute to achieve environmental sustainability goals by preventing waste of resources. As a result of the research, it was also determined that agricultural drones equipped with high-resolution cameras and sensors provide detailed maps of agricultural lands and provide farmers with data on plant health, water, and nutrient deficiencies. This data facilitates more informed decision-making, reducing crop losses and optimizing production processes. In accordance with the study results, it was concluded that product quality and paddy yield increase especially thanks to homogenous planting and fertilisation. This situation will increase the competitiveness of enterprises. In addition, it was observed in the research that the use of agricultural drones directly contributes to both cost reduction and environmental sustainability by optimizing the use of chemicals.

The effectiveness of agricultural drones in agricultural production was also reflected in their impact

on the profitability of businesses. According to the research results, the increase in gross profit was achieved through the efficiency and cost optimization of agricultural drone technology. The increases in gross and net profits showed that agricultural drones offer a low-cost and high-efficiency solution. The increase in the relative profit rate revealed that the profitability and business efficiency obtained from each unit of production have increased. Farmers happily adopted this technology and continued to use it. Studies conducted particularly in the Black Sea region have shown that the use of agricultural drones has increased significantly during the transition period from 2022 to 2023, and that this technology is expected to become even more widespread in the coming years. However, similar analyses need to be repeated at regular intervals to clearly understand the long-term effects of this technology. It is expected that educational programs on the use of digital technologies and the improvement of legal regulations on the subject will accelerate the technological transformation in the agricultural sector, allowing for the wider adoption of agricultural drones and other digital technologies.

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