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RESEARCH ARTICLE

THE IMPORTANCE AND CONTRIBUTION OF PRECISION AGRICULTURE TECHNOLOGIES IN REDUCING GREENHOUSE GAS EMISSIONS

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Abstract

Many measures are being taken worldwide to prevent climate change and drought. In developed countries, efforts in the fields of economy, energy and agriculture continue uninterruptedly. Agriculture is greatly impacted by climate change, and unsustainable farming practices are no exception. The agricultural sector produces significant amounts of greenhouse gases, including CO_2, N_2O, and CH_4.Changing carbon stocks in soil and atmospheric air, due to changes in the energy used in agricultural practices and changes in soil management, affects CO_2 emissions. There has been a recent movement in the agricultural sector to cut greenhouse gas emissions.While existing studies have demonstrated the effectiveness of sustainable agricultural practices in reducing greenhouse gas emissions, there is limited research specifically examining how Precision Agriculture Technologies (PAT) contribute to these reductions.Accordingly, by accounting for the land's temporal and spatial variability, precision agricultural technologies make it possible to use agricultural inputs efficiently. Agriculture productivity is raised by these cutting-edge technologies, which include precision physical weeding, variable rate sowing, irrigation, pesticide application, and fertilization. Precision Agriculture Technologies (PAT) can contribute to reducing greenhouse gas emissions in agricultural activities, sustaining or increasing productivity, in this context, the variable rate approach to fertilization, irrigation and pesticide application has a significant impact. Remote sensing (satellite imagery, thermal imaging), global positioning system (GPS), lidar (light reflection and detection), drones, geographic information systems (ArcGIS), Google Earth and Global Mapper are also used in precision agriculture practices.By analyzing the impact of these practices in reducing greenhouse gas emissions, the advantages of using (PAT) in future agricultural and climate policy measures can be evaluated. In studies, it has been determined that agricultural activities (fertilization, tillage, irrigation, spraying) carried out using precision agriculture techniques reduce greenhouse gas emissions by 5%-62%. At the same time, it is also stated that it contributes to the economy by saving money by using agricultural input at the required rate. Examining how precision

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agriculture technologies might reduce greenhouse gas emissions from agricultural sources is the aim of this review.

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Introduction:-

An increase in certain gases (such as CO_2, CH_4, and N_2O) in the atmosphere is the cause of global warming. By absorbing the sun's rays, these gases create a sort of canopy over the atmosphere. The earth's heat is reflected by this cover, warming our planet [1]. Increasing air temperatures around the world and in our country indicate a significant climate change. This global warming may cause climate zones to change, sea levels to rise, the frequency of flood disasters and the impact of severe weather events to increase, and problems such as desertification, erosion, drought, agricultural pests and epidemics emerge. This can disrupt the natural balance, affecting life forms and human health. It can also have significant consequences on socio-economic sectors and ecological systems [2,3].

The sectors that cause greenhouse gas emissions are energy, transportation, industry and agriculture. Approximately 30% of greenhouse gas emissions are caused by pesticides, chemical fertilizers, and animal waste used in agriculture. As population growth and rising food demand lead to more intensive agricultural processes, this proportion is expected to rise in the future [4]. According to a different study, agricultural practices significantly contribute to climate change, making up around 13.5% of anthropogenic greenhouse gas emissions [5]. The primary ways that agriculture contributes to greenhouse gas emissions are through fertilizer use, animal digestion, and agricultural land cultivation[6]. New technologies used in agriculture are not only improving the sustainability of agriculture, but also increasing production, ensuring food security and reducing greenhouse gas emissions. This is a truly promising development for the future of agriculture [7,8,9]. In recent years, efforts to lower greenhouse gas emissions have significantly increased. Nonetheless, more thorough research ought to be done in order to lower greenhouse gas emissions.

The fact that methane's global warming effect is 25 times larger than CO_2's shows how strongly it affects the atmosphere. The conversion of microbial nitrogen from soil and manure, as well as from the urine and feces of grazing animals, is the primary source of nitrous oxide released into the atmosphere. Nitrous oxide is 298 times more responsible for global warming than CO_2 over a century. Animal manure and synthetic nitrogen fertilizers account for about one-third (37%) of agricultural emissions in Europe [10,11].

There is strong evidence of reduced greenhouse gas emissions and lower agricultural inputs in regions where precision agriculture is commonly practiced. Precision Agriculture Technologies (PAT) refer to advanced tools and techniques, such as GPS, remote sensing, drones, and automated machinery, that enable farmers to monitor andmanage field variability in crops, soil, and other environmental factors with greater precision. These technologieshelp optimize agricultural inputs such as water, fertilizer, and pesticides ensuring they are used efficiently and onlywhere needed. This can improve crop productivity in some cases [12,13,14]. Precision agriculture technologies effectively optimize agricultural inputs by ensuring that they are used efficiently. Variable-rate precision agriculture technologies are used in methods such as variable-rate fertilization, irrigation, pest control, planting and harvesting to increase agricultural production. These technologies can also increase yields by reducing greenhouse gas emissions. Adoption of these variable rate technologies in agricultural activities can reduce GHG emissions as well as strengthen sustainable productivity. This study examined the impacts of using precision agriculture application technologies to reduce GHG emissions.

While existing literature has demonstrated the potential of Precision Agriculture Technologies (PAT) in reducingagricultural inputs and enhancing productivity, fewer studies have specifically examined the mechanisms by whichthese technologies contribute to the reduction of greenhouse gas emissions. Much of the existing research hasconcentrated on individual PAT technologies or components, such as variable-rate fertilization or irrigation, oftenwithout assessing their combined effects or the underlying processes that drive emissions reductions. This studyaims to fill these gaps by providing a comprehensive synthesis of the existing evidence on PAT and greenhouse gasmitigation, with a particular focus on the interactions between different PAT components and their role inoptimizing emissions reductions across diverse agricultural systems. By addressing these aspects, this review offersa more nuanced understanding of how PAT can contribute to sustainable agricultural practices and climate change mitigation.

Methods
This review article is based on an extensive collection and analysis of previously published studies, technical reportsand data related to greenhouse gas emissions in agriculture. Relevant literature was sourced from indexed databases(e.g., Scopus, Web of Science, Google Scholar), to ensure a comprehensive review of current findings in the field.In addition to the literature review, data for figures and tables were primarily obtained from the Turkish StatisticalInstitute (TUIK). The data collected from TUIK were processed and organized using Microsoft Excel to generatevisual representations, including graphs and tables, which illustrate key trends in greenhouse gas emissions overtime. These data points, sourced from TUIK, were then analyzed and interpreted in the context of existing researchto provide a broader understanding of emission trends and the role of Precision Agriculture Technologies inmitigating greenhouse gas emissions.

Results and Discussion

Greenhouse Gas Emissions and Agriculture

The main sources of methane come from various processes such as organic waste decomposition, animal feces, and rice cultivation. Microbial activities in these processes lead to methane production. The primary sources of nitrogen oxides are tillage practices and the application of synthetic nitrogen fertilizers. These fertilizers help plants absorb nitrogen more effectively, but they also cause nitrogen oxides to be released. When fossil fuels are burned in agricultural machinery and vehicles, carbon dioxide is created.CO_2 can also be released in processes such as deforestation or conversion of farmland. Other greenhouse gases can include small amounts of nitrous oxide (N_2O) and other gases. These gases are usually produced during organic matter decomposition, fertilization and agricultural processes. In the agricultural industry, these are the main sources of greenhouse gases. Other factors include fuel use and exhaust emissions from tractors and other agricultural machinery. GHG emissions in the farming sector can generally be reduced by considering farming practices, fertilization methods, waste management and tillage techniques. GHG emissions from agricultural activities and these processes are shown in Figure 1. Approximately 30% of greenhouse gas emissions come from farming activities that use chemical pesticides and fertilizers as well as animal waste [15].

Figure 1:-Major sources of greenhouse gas emissions

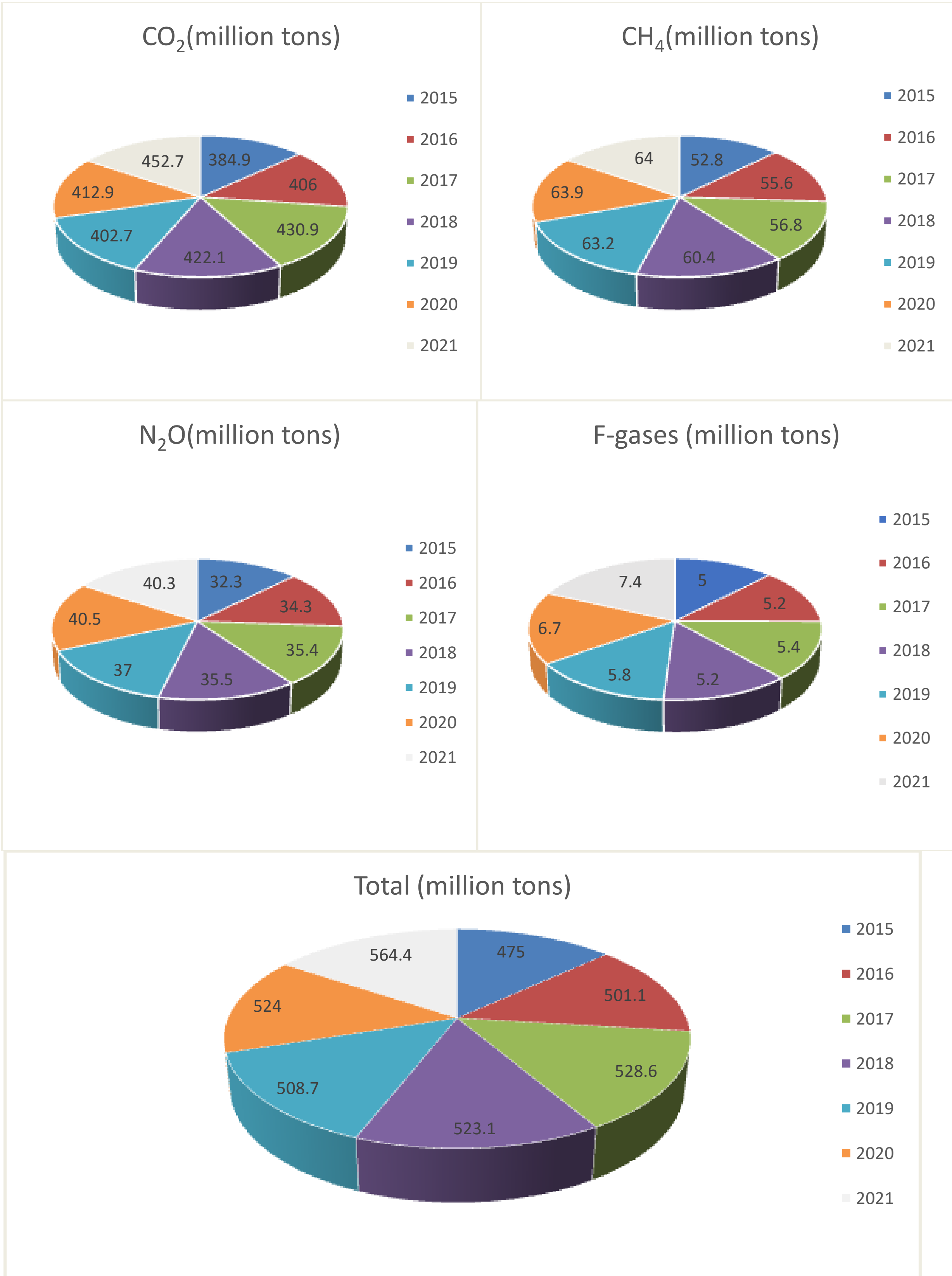

Figure 2:-Yearly Distribution of Different Greenhouse Gases and Total Emissions in Türkiye from 2015 to 2021[16].

As shown in Figure 2 and Table 2, total greenhouse gas emissions have increased over the years. In a study by [17], taking into account 43 different sectors related to global warming and greenhouse gas emissions, it was stated that 32% of total greenhouse gas production originated from industrial processes, 30% from the energy sector, 16% from the transportation sector, 16% from other sectors and 6% from the agriculture sector. According to US Environmental Protection Agency data, the agriculture sector was responsible for about 11% of greenhouse gas emissions in 2020, more than any other sector. Among them are 13% for business and residential use, 13% for land use and forestry, 24% for industry, 25% for electricity generation, and 27% for transportation [8,18,19].

The International Panel on Climate Change's study has emphasized the importance of Türkiye's biodiversity and the necessity of a comprehensive examination of the effects of climate change in Türkiye. Due to its geographical challenges, including soil erosion, drought, and water scarcity, Turkey is among the nations that will be most severely impacted by global warming [20].

Table 1:- Total greenhouse gas emissions (CO_2 equivalent) by sector in Türkiye,1990 – 2021 [16].

(Million tons)						
Year	Total	Change from 1990 (%)	Energy	Industrial processes and product utilization	Agriculture	Waste
1990	219.5		139.5	22.9	46.1	11.1
1991	226.8	3.3	144.0	24.6	46.9	11.3
1992	233.1	6.2	150.3	24.3	47.0	11.5
1993	240.8	9.7	156.8	24.8	47.4	11.8
1994	234.4	6.8	153.3	24.1	44.9	12.0
1995	248.2	13.1	166.3	25.5	44.1	12.3
1996	267.6	21.9	184.0	26.2	44.8	12.7
1997	278.8	27.0	196.1	27.0	42.5	13.2
1998	280.3	27.7	195.8	27.3	43.7	13.5
1999	277.8	26.5	193.8	25.8	44.3	13.9
2000	298.9	36.2	216.0	26.2	42.3	14.3
2001	279.7	27.4	199.2	25.8	39.9	14.8
2002	285.6	30.1	206.0	26.8	37.6	15.2
2003	304.8	38.8	220.5	28.2	40.6	15.6
2004	314.4	43.2	226.3	30.8	41.3	16.1
2005	337.6	53.8	244.5	34.3	42.4	16.4
2006	358.0	63.1	260.5	36.8	43.9	16.8
2007	391.7	78.4	291.5	39.7	43.4	17.1
2008	388.5	77.0	288.3	41.7	41.3	17.2
2009	395.2	80.0	292.9	43.1	42.0	17.2
2010	398.8	81.7	287.9	49.1	44.4	17.4
2011	428.6	95.2	310.0	54.0	46.9	17.8
2012	448.2	104.2	321.6	56.3	52.7	17.6
2013	440.2	100.5	308.3	59.3	55.9	16.7
2014	459.5	109.3	326.7	60.1	56.2	16.5
2015	475.0	116.4	342.0	59.7	56.1	17.1

2016	501.1	128.3	361.7	63.8	58.9	16.7
2017	528.6	140.8	382.4	66.6	63.3	16.3
2018	523.1	138.3	373.4	67.7	65.3	16.6
2019	508.7	131.7	365.6	59.0	68.0	16.1
2020	524.0	138.7	366.6	68.0	73.2	16.3
2021	564.4	157.1	402.5	75.1	72.1	14.7

According to TUIK data for 2021, when total greenhouse gas emissions are convertedinto CO_2 equivalents, energy-related emissions were the largest source of emissions with a share of 71.3%. Waste (2.6%), agriculture (12.8%), and industrial processes and crop use (13.3%) came next. Emissions from the energy sector were projected to reach 402.5 $MtCO_2$ equivalent in 2021, up 9.8% from the year before and up 188.4% from 1990. The estimated emissions from product use and industrial processes in 2021 were 75.1 $MtCO_2$ equivalent, which was 10.6% more than the previous year and 228.7% higher than 1990. The estimated emissions from the farm sector in 2021 will be 72.1 $MtCO_2$ equivalent, up 56.5% from 1990 and down 1.5% from the year before. Last but not least, waste sector emissions decreased 9.9% annually to 14.7 $MtCO_2$ equivalent, up 32.6% from 1990 [16]. Table 2, Figure 3 and Figure 4 show the total GHG emissions and their sources by sectors between 1990 and 2021. Accordingly, in general, GHG emissions have increased as the years have increased.

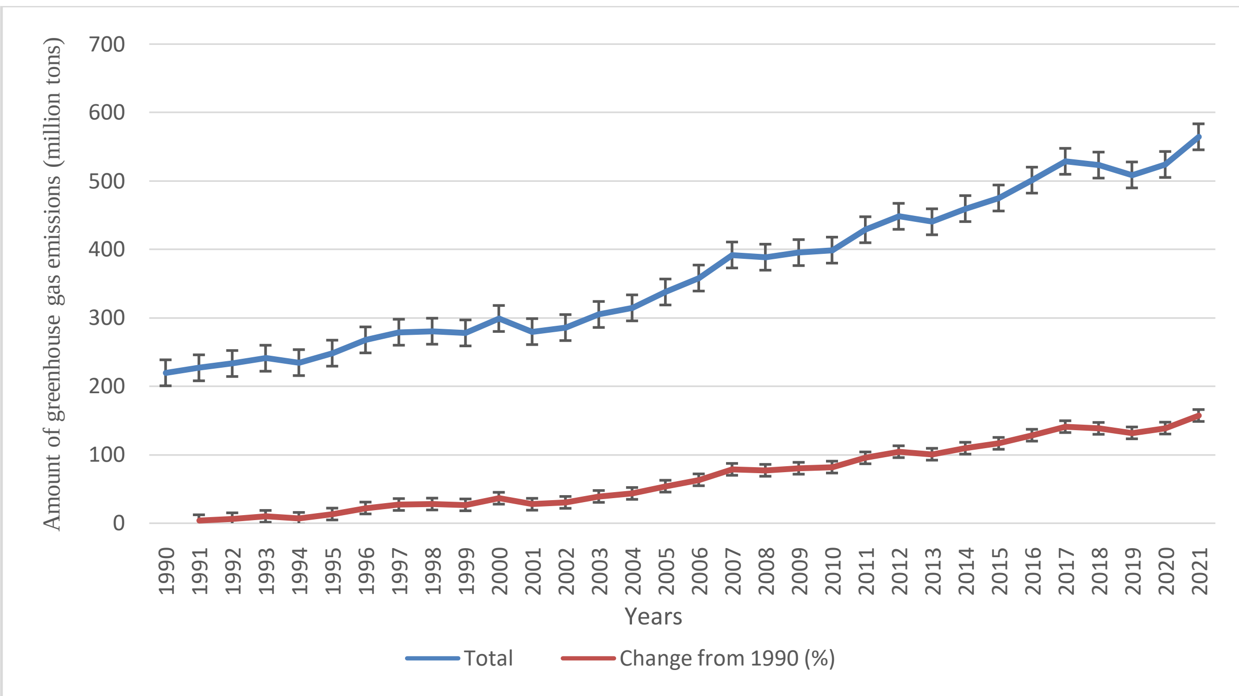

Figure 3:- Total greenhouse gas emissions and percentage changes in Türkiyeover the years compared to 1990[16].

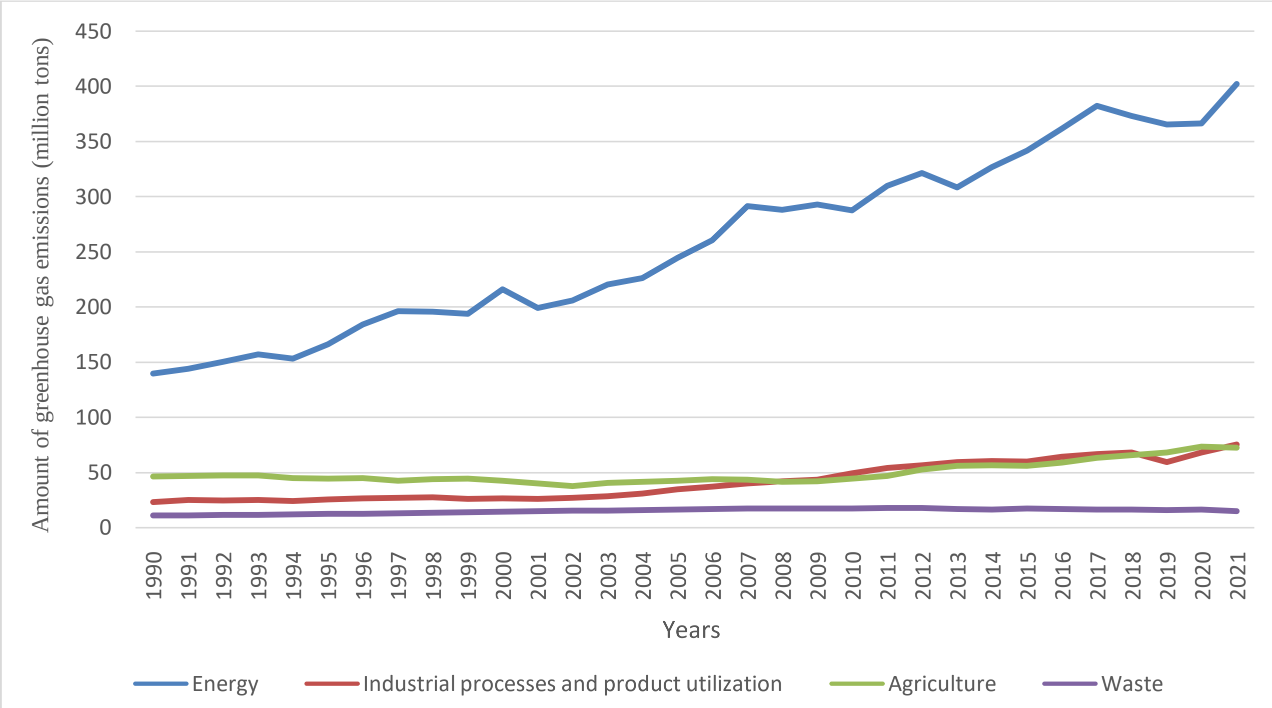

Figure 4:- Amount of greenhouse gas emissions by sectors in Türkiye between 1990-2021 [16].

Table 2:- Greenhouse gas emissions (CO_2 equivalent) in Türkiye, 1990 - 2021 [16].

(Million tons)					
Year	Total	CO_2	CH_4	N_2O	F-gases
1990	219.5	151.6	42.5	25.0	0.5
1991	226.8	158.1	43.4	24.7	0.6
1992	233.1	164.1	43.3	25.3	0.5
1993	240.8	171.1	43.1	26.0	0.5
1994	234.4	167.6	42.8	23.6	0.5
1995	248.2	181.4	42.6	23.9	0.4
1996	267.6	199.6	43.0	24.5	0.4
1997	278.8	212.1	42.2	24.1	0.4
1998	280.3	212.1	42.4	25.3	0.4
1999	277.8	207.9	43.8	25.6	0.4
2000	298.9	229.9	43.7	24.8	0.5
2001	279.7	213.6	42.9	22.6	0.7
2002	285.6	221.2	41.0	22.6	0.8
2003	304.8	236.8	43.0	24.0	1.1
2004	314.4	244.8	43.5	24.8	1.4
2005	337.6	264.9	45.2	26.0	1.6
2006	358.0	282.4	46.6	27.2	1.8
2007	391.7	313.7	49.1	26.8	2.2
2008	388.5	310.6	50.2	25.4	2.3
2009	395.2	316.4	49.9	26.6	2.3
2010	398.8	316.2	51.6	27.4	3.5
2011	428.6	342.1	54.2	28.5	3.9
2012	448.2	356.1	57.8	29.7	4.6
2013	440.2	347.3	56.7	31.5	4.7
2014	459.5	364.0	58.5	31.7	5.2

2015	475.0	384.9	52.8	32.3	5.0
2016	501.1	406.0	55.6	34.3	5.2
2017	528.6	430.9	56.8	35.4	5.4
2018	523.1	422.1	60.4	35.5	5.2
2019	508.7	402.7	63.2	37.0	5.8
2020	524.0	412.9	63.9	40.5	6.7
2021	564.4	452.7	64.0	40.3	7.4

F-gases are fluorinated gases

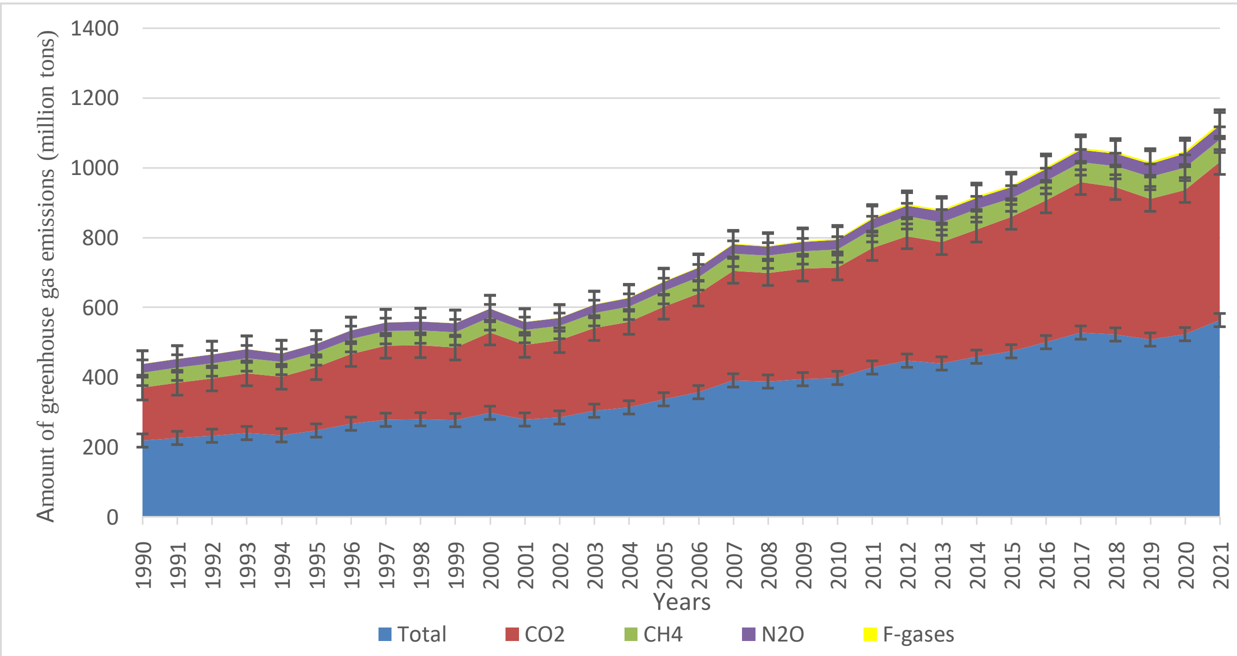

Figure 5:- Greenhouse gas emissions in Türkiye by years [16].

According to TUIK's 2021 report, 32.7% of total CO_2 emissions came from energy-related activities such as electricity and heat generation. The second-largest contributor, at 14.5%, was the industrial processes and product use sector, followed by the agriculture and waste sectors at 0.3%. Methane (CH_4) emissions were primarily from the agricultural sector (61.4%), followed by the energy sector (19.3%), the waste sector (19.3%), and the industrial processes and product use sector (0.03%). Nitrous oxide (N_2O) emissions were primarily from the agricultural sector (78%), followed by the energy sector (11.1%), the waste sector (5.9%), and the industrial processes and product use sector (5%) [16]. According to the data between 1990-2021 in Table 2 and Figure 5, it is seen that greenhouse gas emissions in general have increased over the years.

Table 3:- Literature examples of precision agriculture practices.

Precision agriculture practice	**Functions**	**Source**
The minimum /zero amount of soil cultivation	It enhances water infiltration and organic matter eclipse by reducing energy consumption along the land providence.	[21].
Air-based Crop Farming consultancy	It is a system that uses technology to forecast the weather, gather data about the climate, and offer advice to farmers.	[22].
Livestock Climate-Smart Housing	In order to protect animals from severe heat or cold stress, it uses technology to assist farmers in making timely, focused decisions.	[23].
Site-Specific Integrated Nutrient Management	Optimizes the soil nutrition supply based on crop type, site, and season.	[24].

Leaf Color Charts	It is used to detect nitrogen deficiencies in crops such as wheat and maize by determining the amount of nitrogen required based on the crops' degree of greenness.	[25].
Intercropping Legumes and Green Manuring	These two methods are employed to improve the nitrogen supply and soil quality.	[26].
Enhanced Crop Types	Offers a risk management strategy to get ready for various weather events, including drought, floods, and heat or cold stress.	[27].

Precision Agriculture Technologies

Precision agriculture technologies provide significant benefits at every stage of the agricultural process. By increasing agricultural productivity, they allow for healthier and more efficient products. It also makes significant contributions in terms of time management, because it minimizes crop losses by ensuring that work is done on time and correctly. In terms of economic returns, precision agriculture offers the opportunity to generate higher incomes by utilizing technological resources and increases farmers' profitability. In terms of sustainability and environmental protection, it guarantees environmentally friendly agricultural production and minimizes environmental effects by using fewer chemical inputs. In terms of product quality and marketability, quality and timely products are obtained, enabling farmers to market their products at higher prices. At the same time, in terms of labor productivity, the use of technology enables workers to work more efficiently, reducing workload and increasing work productivity. Therefore, precision agriculture technologies offer many advantages for both farmers and the environment in the agricultural sector [28].

The Role of Precision Agriculture in Reducing Greenhouse Gas Emissions

Precision farming technologies play a key role in reducing greenhouse emissions. They reduce chemical use by optimizing fertilizers and pesticides applied to crops, reduce water consumption by making irrigation systems and water management more efficient, and reduce carbon dioxide levels by increasing carbon storage capacity through soil management. It also uses plant breeding techniques and genetic optimization, enabling the cultivation of crops that cause fewer greenhouse gas emissions. In this way, precision agriculture contributes to a more sustainable agricultural model by reducing the environmental impacts of agriculture. Techniques that seek to apply agricultural inputs (fertilizers, water, pesticides, etc.) at the appropriate time, location, and quantity are attempted to be explained under the following headings under the umbrella of precision agriculture or "smart agricultural technologies."

Variable Rate Fertilization

Variable rate nutrient applications provide the necessary nutrients to the field by adjusting the nutrient application interval according to field maintenance. This system determines the needs of the plants in the field and ensures that the right amount of fertilizer is applied, thus increasing productivity and making more efficient use of resources.

Plants need essential nutrients to perform different metabolic processes. These essential nutrients are the main macronutrients called Nitrogen, Potassium and Phosphorus. The quality, growth, and productivity of plants are significantly impacted by these nutrients. Furthermore, secondary macronutrients like magnesium (Mg) and calcium (Ca) are crucial for plant growth.Nitrogen inorganic fertilizers cause N_2O and CO_2 emissions during the manufacture process and also lead to N_2O emissions after being applied to the soil. Thus, nitrogen fertilization has a very important impact on greenhouse gas emissions in the agriculture industry[29,30,31,32].

Research has shown that most farmers use more nitrogen than they need [33]. The average nitrogen surplus for the 28 EU members in 2016 was 51 kg N/ha, including biological fixation by free-living organisms, seeds and legume crops, organic and inorganic fertilizers, and other nitrogen inputs, according to Eurostat data. This indicates how much nitrogen fertilizer can be cut back on in agricultural production. From 2009 to 2012, nitrogen surplus in the EU-28 countries fell to an average of 48 kg N per hectare. This shows a decreasing trend in nitrogen use [34].

Variable rate fertilizer application ensures optimal use of nitrogen according to product requirements. This method lowers greenhouse gas emissions by using less fertilizer in the end. Both CO_2 (from fuel decrease and fertilizer quantity reduction due to timely fertilization) and N_2O (from N fertilizer crop and use) emissions are reduced. CH_4 emissions can also be reduced during the fertilization process. Moreover, GHG emissions can be further decreased when N fertilization is coupled with rainfall forecasting or appropriate irrigation scheduling [35].

Research on the impact of nitrogen applications on N_2O emissions is adequate, despite the lack of conclusive evidence regarding the effectiveness of variable rate nitrogen applications in reducing GHG emissions. Reported the potency for a 5% decrease in mineral fertilizer use. It was also underlined that a 5% reduction in the application of mineral fertilizer relative to the baseline emission rate could be accomplished through the efficient use of variable rate technology[36]. Establish that nitrogen fertilizer use rates are related to N_2O emissions [37,38]. According to another study, roughly 1.19% of the nitrogen that is added to the soil is released as N_2O[39]. Stated that N_2O emissions can be directly reduced by reducing nitrogen inputs [40]. It has been discovered that field nitrogen applications using GPS and variable rate nitrogen application can cut N_2O emissions by up to 34%[41]. Reported a rise in wheat crop by 1% to 10% and a saving of 4% to 37% in nitrogen fertilization [42]. Comparing irrigation systems in Colorado, showed that variable rate fertilization with nitrogen always yields better results than conventional methods, saving between 6% and 46% [43]. There is strong evidence that in areas where Precision Agriculture is widely adopted, reductions in water and fertilizer use of 20% to 40% can be achieved. In some cases, it has also been shown to increase yields [44,45,46].

Figure 6:- Variable rate fertilization.

Variable Rate Irrigation

Irrigation promotes bacterial activity by increasing anaerobic conditions, leading to the release of more CH_4 gas. This suggests that irrigation techniques can significantly affect greenhouse gas emissions. Additionally, variations in soil humidity have an impact on the redox potency of the soil, which significantly changes the amounts of greenhouse gas emissions in the soil. Therefore, irrigation practices should be reviewed, and water quantity should be determined taking into account plant irrigation needs. With variable rate irrigation technology, plants' water needs are adjusted based on time and location, increasing irrigation efficiency and lowering greenhouse gas emissions. Recent studies show that drip irrigation can importantly decrease greenhouse gas emissions in the soil and at the same time protect air quality without jeopardizing food product manufacture. However, the quantity of irrigation and nitrogen fertilization are exactly related with N_2O emissions [8,18,34]. This study shows that underground drip irrigation reduces CO_2, N_2O and NO emissions by up to 62% [11]. Nitrogen fertilization can further reduce GHG emissions when combined with accurate rainfall forecasting or scheduled irrigation. Thus, drip irrigation systems effectively reduce GHG emissions. Furthermore, plant water fertility can be improved by an optimal irrigation programme [8,11,18,22]. The irrigation technique can help reduce greenhouse gas emissions by adjusting the amount and timing of irrigation.

Irrigation techniques can be optimized with the use of variable rate irrigation systems. Because fields are not homogeneous, if water is distributed evenly, some areas may be over-irrigated while others remain dry. This not only reduces yields, but also affects greenhouse gas emissions. Variable-rate irrigation technology has the potency to decrease over-irrigation, under-irrigation and flow, which improves soil welfare and protects the ecosystem. Effective water use is the foundation for variable rate irrigation's ability to lower greenhouse gas emissions. Furthermore, appropriate irrigation schedules prevent excessive soil moisture use, which increases N_2O emissions. Using variable rate irrigation technology, irrigation water can be recorded by about 8-20%. Many other studies have also reported that variable-rate irrigation technology leads to reduced water use and increased irrigation efficiency [11,18]. As a result, soil water use, which influences irrigation quantity, timing, and technique, is correlated with GHG emissions.

In comparing N_2O emissions from irrigated and non-irrigated regions, Trost et al. discovered that irrigation significantly increased N_2O emissions (by 50% to 140%)[47]. According to this research, N_2O emissions from irrigated soils can be considerably impacted by varying the rate of irrigation. In order to maintain soil water levels, variable-rate irrigation systems can also be used in conjunction with fertilization plans and weather forecasting models to schedule irrigation.

Figure 7:- Variable rate irrigation.

Controlled Agricultural Traffic

A lot of tractor power is needed when implementing agricultural activities. Tractors are used in many applications such as fertilization, spraying and tillage. Intensive field traffic causes soil compaction and excessive tillage causes greenhouse gas emissions. Reducing soil compaction means better yields and sustainability in agriculture. This approach prevents crop losses, optimizes water and nutrient use, maintains soil quality and reduces costs. The result is a more efficient and healthy agricultural process.

Controlled traffic farming can lower greenhouse gas emissions by reducing the amount of input used in agricultural activities. Grain production can reduce fuel costs by 25–27%, according to a Danish study that looked at the effects of district-specific use and check traffic systems on large farms (300 hectares and up). At the same time, savings of 3-5% in fertilizer and pesticide use can be achieved compared to conventional fertilizer and pesticide applications [48]. A healthy soil structure helps the soil absorb greenhouse gas emissions and prevent the production of harmful gases. In a traffic-free field, the number and size of pores increases, allowing more water to be absorbed and retained by the soil. This means not only a reduced risk of runoff and erosion, but also that plants have access to more water and productivity increases. Increased yields can lead to more carbon being stored in crops and reduced greenhouse gas emissions.

A study by Tullberg examined the impact of check agricultural traffic on greenhouse gas emissions [49]. By facilitating zero soil cultivation, lowering energy inputs, and increasing fertilizer sufficiency, this approach seeks to lower GHG emissions. The study found that compared to conventional tillage methods, opting for zero tillage in unchecked traffic and zero soil cultivation in check traffic resulted in a reduction in tractor fuel requirements of up to 40% and 70%, respectively. The use of controlled agricultural traffic can reduce fertilizer use by 10-15% and pesticide use by up to 25% [49]. [50], pointed out that controlled traffic farming reduces fuel use by at least 35% in the process of growing crops, while [48], mentioned that it can reduce fuel costs by 25-27% in grain production.

Controlled agricultural traffic maximizes dry matter production and water use by maintaining soil health and mimicking the natural structure of vegetation. This increases soil carbon storage capacity and positively affects soil fertility. This positively supports environmental impact by reducing greenhouse gas emissions.

Figure 8:- Images of soil tillage.

Variable Rate Pesticide Application

Technologies that enable changing pesticide application rates enable the area to supplement existing or potently harmful stressors. By doing this, pesticides are not applied to undesirable parts of the fields or plant canopies [51]. According to [52], these technologies are also utilized to apply fertilizers at varying rates. Applying lower concentrations of pesticides without going over the use rates specified for the specified disease, pest, or weed species is possible with changing rate technologies. Additionally, less chemical use may result from this, which may affect the final crop's quality. In light of rising crop prices, this could increase the farm's profitability. Reducing the use of pesticides has significant ecological benefits. The environmental advantages of less pesticide use include decreased pollution of the soil and water as well as less detrimental effects on biodiversity [53]. Furthermore, constraining the utilize of insecticides and applying pesticides sensitively can reduce pest damage, increase crop yields and farmers' profits [54]. There are significant studies on the savings in herbicide use in different crop species, ranging from 11% to 90% [53,55,56]. Research indicates that the use of pesticides in perennial products can be decreased by 28% to 70% [57,58]. It has been reported that variable rate pesticide applications can reduce insecticide use in winter wheat by 13.4% [59].

Figure 9:- Variable rate pesticide application.

Variable Rate Sowing

Plant or seed rates are modified using the changing rate planting technique based on the potential of the local soil. Unlike traditional seeding machines (seed drills, etc.), which rely on planting seeds or plants in a predetermined ratio, variable-rate seeding systems utilize an independent gearbox or hydraulic system that can be adjusted to suit the needs of a specific area of the field[60]. The total amount of plants or seeds used in the region is probably going to be less with variable rate planting, which translates into fewer greenhouse gas emissions from the manufacturing of the plant or seed. Additionally, through higher yields, it is anticipated to positively impact GHG emissions [61]. Additionally, variable rate planting can reduce greenhouse gas emissions by reducing the amount of fuel needed to produce the same amount of harvest because more harvesting can be produced on a dedicated soil surface.

Figure 10:- Variable rate planting application.

Conclusion:-

Greenhouse gas emissions must be decreased in order to combat global climate change. In this sense, the agricultural sector is a major source of greenhouse gas emissions into the atmosphere, and coming up with innovative ways to reduce these emissions will be necessary. Precision agriculture technologies offer an effective solution to this problem. These technologies, which are designed to maximize agricultural output, make sure that fertilizer, pesticides, and water are applied at the appropriate time and quantity. This increases the efficiency of agricultural activities and reduces greenhouse gas emissions. Another important benefit of precision agriculture technology is their positive impact on soil health. These technologies promote soil carbon storage by preserving the soil's natural equilibrium, which eventually lowers carbon emissions. It offers sustainable water management solutions in addition to improved irrigation systems and more effective use of water resources. Integrated pest management practices are another advantage of precision agriculture in terms of protecting and enhancing biodiversity. These approaches enable farmers to achieve higher yields while providing environmental and economic benefits. Additionally, by using fewer inputs, precision agriculture techniques like variable rate planting, fertilization, and spraying are crucial in reducing greenhouse gas emissions. All of these technologies are acknowledged as crucial instruments in the battle against climate change and improve the sustainability of agriculture. Adoption of these technologies, which will determine the direction of the agricultural sector in the future, will contribute to the creation of more sustainable and environmentally friendly production systems.

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