Scientific Papers. Series E. Land Reclamation, Earth Observation & Surveying, Environmental Engineering. Vol. XIII, 2024
Print ISSN 2285-6064, CD-ROM ISSN 2285-6072, Online ISSN 2393-5138, ISSN-L 2285-6064

DETERMINING GREENHOUSE GAS EMISSIONS RESULTING FROM ENERGY AND WATER CONSUMPTION FOR THE DECARBONIZATION OF CORN PRODUCTION AND DEVELOPING STRATEGIES TO REDUCE THE CARBON FOOTPRINT

Hasan Hüseyin ÖZTÜRK[1], Bülent AYHAN[2], Serdar AYGÜN[3], Ali GÜL[4], Serkan KARABAĞLI[4]

[1]University of Cukurova, Faculty of Agriculture, Sarıcam, Adana, Türkiye
[2]Ministry of Agriculture and Forestry, Adana Agricultural Production and Agricultural Extension and Training Center, Adana, Türkiye
[3]General Directorate of Meteorology, Keçiören, Ankara, Türkiye
[4]Ministry of Agriculture and Forestry, Department of Education and Publications, Ankara, Türkiye

Corresponding author email: hhozturk@cu.edu.tr

Abstract

This study aimed to determine greenhouse gas emissions (GHG) resulting from energy and water consumption in corn production and to define carbon footprint (CFP) indicators. As fuel consumption for corn production processes, diesel fuel and engine oil consumed by the tractor engine were taken into account. In the calculations made to determine carbon dioxide (CO_2) emissions resulting from fuel use, the fuel-based CO_2 emission calculation method recommended by the Intergovernmental Panel on Climate Change (IPCC) have been followed. The individual determination of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions related to fuel consumption and their conversion into CO_2 equivalent emissions are explained. The environmental sustainability effectiveness of corn production was evaluated as the carbon footprint (CFP) of energy and water consumption. Carbon footprint indicators for energy and water consumption have been defined.

Key words: *carbon footprint, fuel, greenhouse gas emissions.*

INTRODUCTION

For sustainable agricultural production, it is necessary to use energy more effectively in agricultural production processes and reduce the use of fossil fuels. For this reason, sustainable production systems that consume less fossil energy, are efficient, and will reduce greenhouse gas emissions (GHGs) should be developed. In order to combat climate change, efforts are being made to control and reduce the increase in GHGs that cause global warming. For this reason, it becomes important to analyze GHGs in agricultural production.

In today's world, the constant increase in the prices of energy resources due to the decrease in energy resources based on fossil fuels and their negative effects on the environment, and the decrease and pollution of water resources are important global problems. Therefore, it is necessary to ensure the sustainability of agricultural practices in order to use energy and water resources efficiently and to reduce the effects of all inputs used in agricultural production on global climate change. In a global context, the proposed research will contribute to the efficient use of energy and water resources by end users/consumers and to reduce the input costs using these resources.

The agricultural sector is in a position to meet people's nutrition and shelter needs, provide raw materials to industry and therefore have a positive impact on the country's economic development process. Agricultural ecosystems are negatively affected by climate change. This situation causes serious environmental, social and economic impacts. However, in one aspect, the agricultural sector triggers climate change with greenhouse gas emissions (EEA, 2023). In other words, the agricultural sector is in a position to both be affected by and trigger climate change. Harmful substances in exhaust emissions are released into the atmosphere and pollute the environment due to reasons such as the use of fuel and engine oil in agricultural production, not choosing agricultural tools and machines with power and design suitable for production processes, and overloading of engines. In addition, as the food demand of the ever-increasing population is met by increased agricultural production, it also leads to an increase in GHG emissions.

Reducing the carbon footprint (CFP) is one of the key goals to be achieved in order to limit the overall environmental impact of agriculture. Another important goal is to reduce the use of crop preservative chemicals, which have the negative impact of disrupting essential food webs in and around fields. The agricultural sector contributes significantly to global carbon emissions from a variety of sources, including product and tool and machinery manufacturing, material transportation, and direct and indirect GHG emissions from soil. The agricultural sector is a sector that contributes significantly to global carbon emissions through the production and use of agricultural machinery, crop protection chemicals (pesticides) and fertilizers. The CFP, the total amount of GHG emissions associated with a product throughout the supply chain. Often times, a carbon footprint refers to the amount of GHG something creates, specifically the amount of carbon dioxide (CO_2), methane and nitrous oxide. CO_2 emissions from fertilizer, electricity, machinery, chemicals and fuel production processes are considered to calculate the total carbon footprint. When calculating the CFP, direct and indirect carbon emissions related to the inputs used in agricultural production processes are considered.

There are many methods and practices to reduce the CFP in agriculture. To calculate the total CFP, carbon dioxide This study aimed to determine GHGs emissions resulting from energy and water consumption in corn production and to define some indicators for the CFP. As fuel consumption for corn production processes, diesel fuel and engine oil consumed by the tractor engine were considered.

Justification for the Decarbonisation

The greenhouse gases (GHG) emissions cause climate change. Projected scenarios of the impact of climate change are less water and higher temperatures. These effects mean that more efficient use of water for pasture and livestock farming and radical changes in livestock practices must promote water conservation and heat tolerance. Adaptation strategies should encourage conservation and efficient consumption of feed. Climate change will also encourage the proliferation of pests and diseases, thereby reducing livestock productivity. As natural ecosystems respond to changing temperatures and precipitation, the ranges of many organisms are expected to expand or change, and new pest and disease combinations are expected to emerge. An increase in the frequency or severity of extreme weather events, such as droughts, heat waves, storms or floods, can also disrupt predator-prey relationships that normally keep pest populations in check. Carbon dioxide (CO_2) concentration has approached more than 50% of the pre-industrial level. Although the CO_2 concentration was 280 ppm in the 1760s, it is now around 410 ppm and is expected to reach 590 ppm by the end of 2100 (Öztürk, 2024a).

The efficiency and profitability of agricultural production depends on energy consumption. Today, agricultural production technologies are developing rapidly and aiming for higher profitability. However, despite all efforts, exhaust emissions from fuel and engine oil consumption of tractors and other agricultural machinery still exceed permissible limits. Inappropriate operating regimes due to improper selection of agricultural tools and machines for the production processes and overloading of engines have negative effects on the environment. In such cases, harmful substances, petroleum products and smoke in exhaust emissions are released into the atmosphere. These emissions cause significant damage to natural environmental ecosystems.

Contribution of Agricultural Production to GHG Emissions

Agriculture has a special importance in terms of climate change. The relationship between agriculture and climate change is bidirectional. Agriculture is a major emitter of greenhouse gases. Research on this subject show that agricultural production is responsible for approximately 16-27% of all anthropogenic emissions. Global emissions from agricultural production are around 21-25% (Öztürk, 2024a). Agricultural emissions are an important component of *food supply chain* emissions.

Direct and indirect fossil fuel consumption causes various greenhouse gas emissions, especially CO_2, N_2O and CH_4. Greenhouse gases from agriculture and other human activities warm the Earth's surface by absorbing atmospheric infrared radiation and heat energy. This warming effect caused the global temperature on earth to increase in the 20th century. Burning fossil fuels causes more than 75% of GHG emissions from human activities. Today, agricultural production is largely based on the consumption of fossil fuels. Fossil energy consumption causes direct negative effects on the environment through the release of CO_2 and other GHGs. In agricultural production, sustainable agricultural product production by reducing the use of fossil energy is very important. Sustainable agricultural production can be achieved by using energy more efficiently in agricultural production processes and reducing the use of fossil fuels. In order to develop sustainable production systems that require less fossil energy and at the same time provide satisfactory efficiency and reduce greenhouse gas emissions, fossil energy must be used efficiently in agricultural systems.

The energy sector makes the largest contribution to global CO_2-eq. emissions. In the energy sector, two-thirds of total CO_2-eq. emissions are caused by the burning of fossil fuels for power generation. While the global total annual CO_2-eq. of food systems for the period 2007-2016 are estimated to be between 21-37%, it is estimated that 21% of the CO_2-eq. emissions in the same period originate only from agricultural production. Industrial processes are responsible for 8% of total GHG emissions (Öztürk, 2024a).

The contribution of agricultural production to GHG emissions is gradually decreasing. The contribution of agricultural production to GHG emissions averaged 29% in the 1990s (1990-1999). This contribution was 25% in the 2000s (2000-2009) and 20% in recent years (2010-2017) (Öztürk, 2024a).

CO_2 emissions are a byproduct of the production processes of energy resources such as machinery, fertilizers, electricity and chemicals. Using diesel fuel on the farm also emits large amounts of gas. Average total emissions in wheat and paddy production are reported as 900.9 kg CO_2/ha and 1762.5 kg CO_2/ha, respectively. Diesel fuel use is the highest emission source in paddy production, accounting for 55.34% of total CO_2 emissions. On the other hand, it is reported that the highest source of CO_2 emissions in wheat production is fertilizer with 49.7% of total emissions (Ashraf et al., 2021).

Emissions from crop and animal production activities continued to increase over the entire period of 2000-2018. These emissions were 14% higher in 2018 compared to 2000. Emissions related to agriculture and land use decreased from 24% to 17% of global GHG emissions from all sectors in 2018. Agricultural activities for crop and animal production emit significant amounts of non-CO_2 emissions such as the potent GHGs CH_4 and N_2O. Agricultural production accounted for 42% of total CH_4 emissions and 75% of N_2O emissions in 2017. CH_4 and N_2O emissions totalled 5.3 GtCO_2-eq. in 2018. Two-thirds of this total comes from animal production. In particular, CH_4 emissions from enteric fermentation in the digestive systems of ruminant animals remained the largest and only component of agricultural emissions (2.1 GtCO_2-eq.) in 2018 (Öztürk, 2024a).

It is estimated that the agricultural sector directly emitted 629 MtCO_2-eq. in 2019. CO_2 accounts for only 1% of GHG emissions directly related to agriculture. N_2O and CH_4 are the main greenhouse gases released from agricultural activities. Agricultural activities originate approximately 60% of the nitrogen dioxide released into the atmosphere and approximately 50% of the methane. Total N_2O emissions from agriculture amount to 364 MtCO_2-eq. This value accounts for 58% of the total agricultural CO_2-eq. in 2019. 28% of the CO_2-eq. released in the agricultural sector in 2019 resulted from the release of CH_4 released from enteric fermentation. 10% of CO_2-eq. in the form of CH_4 comes from manure management (Öztürk, 2024a).

In plant and animal production, the relative contribution of each process to GHG emissions has not changed significantly over the past two decades. N_2O emissions from chemical fertilizers and plant residues had a proportional increase of more than 35% in 2018. These emission values are in line with the increase in crop production globally and the increase in the use of chemical fertilizers worldwide. The increase in the number of animals increased the increase in emissions from manure and enteric fermentation. These increase rates were 20% and 13%, respectively, in 2018 compared to 2000. Finally, emissions from paddy cultivation, fertilizer management systems and organic soils increased by about 7% in the period 2000−2018 (Öztürk, 2024b).

Energy Consumption in Agriculture

Water, energy and food production are inextricably linked. The agricultural sector uses 11% of the world's land surface, and irrigated farming practices use 70% of the global water resources (Öztürk, 2023a). Drought and reduced agricultural irrigation generally limit production in irrigated areas. As many important food production systems depend on groundwater, poor aquifer levels and groundwater depletion put local and global food production at risk. Increasing food production alone is not enough to ensure food security and eradicate hunger. Efforts to promote food production should be complemented by policies that increase household access to food, either by creating jobs or establishing effective programs.

Approximately 30% of the total water consumption in Europe takes place in the agricultural sector. However, the amount of water consumed in agricultural production in many southern countries of Europe reaches 70% of the total water consumption in these countries. In recent years, regardless of the energy aspect, significant water savings have been achieved and there have been significant increases in energy consumption. In countries such as Spain, the amount of electricity consumed in agricultural irrigation reaches up to 3% of the total national electricity consumption (Öztürk, 2023a).

Essential Measures to Reduce the Impact of the Agricultural Sector on Climate Change in Turkey

Significant progress is being made in reducing greenhouse gas emissions and combating climate change in Turkey. When the policies put forward for various purposes such as the protection of natural resources, sustainable development and protection of the environment, the legal situation, the institutional structure, the projects being implemented and the resources allocated are examined, it is seen that there is a potential that cannot be underestimated. Steps can be taken by reviewing the current structure regarding climate change and making new regulations.

Measures for the Short Term

The problems that need to be solved in the short term can be summarized as follows:

A unit operating in the monitoring and evaluation of climate change and greenhouse gas emissions should be established within the Ministry of Agriculture and Forestry. This unit should undertake important duties such as determining and collecting data on the subject, creating databases, making and publishing calculations, and coordinating Ministry units. These tasks should be:

- Making and recording phenological (temporal monitoring of vital stages of plants such as germination, tillering, flowering) observations throughout Turkey.
- Monitoring land use changes, especially changes that would be detrimental to agricultural and pasture lands.
- Monitoring the carbon content of soils.
- Ensuring the establishment of the Drought Monitoring System and Drought Early Warning and Management System provided in the Drought Action Plan and operating the system together with climate change policies.
- Determining the sources of greenhouse gas emissions resulting from plant and animal breeding activities and continuing activities to raise awareness in the society.
- Ensuring that R&D activities related to the subject are announced to the relevant units and the public.
- Continuing to work on fulfilling international obligations.
- Establishing geographic information systems-databases where all data are compiled, processing and evaluating the information.
- Carrying out monitoring and evaluation of environmental data related to the sector.
- Keeping inventories regarding agricultural infrastructure projects and determining their effects in the fight against climate change.
- Establishing policies and creating legal regulations (Legal requirement, regulation, instruction).

Measures for the Medium Term

➢ There is no information collection, recording, reporting and monitoring systems in accordance with the Kyoto Protocol and the UN Framework Convention and emission information originating from the agricultural sector.

- There are no emission calculations in the crop production and aviation sectors, which are among the sectors that cause the highest greenhouse gas emissions.
- There are no records and statistics regarding fuel usage preferences and fuel preferences used for crop and animal production.

➢ Incentive policies and practices to expand the use of alternative fuels and environmentally friendly vehicles are insufficient.

- The tax exemption provided to biodiesel for agricultural vehicles is insufficient.
- The recording and monitoring system is insufficient for the policy of increasing the use of biofuels.

➢ Nationally Appropriate Mitigation Action NAMA as a financing source, carbon market and emission trading related activities are few and there is no implementation practice.

➢ There is no mechanism to examine/monitor the contribution of all kinds of investments, whether budget resources, foreign loans or public-private partnerships, to the strategy of preventing climate change and reducing greenhouse gases.

➢ There is a lack of knowledge, awareness of decision makers, experts and planners, as well as all users and the public, on sustainable and environmentally friendly transportation issues.

➢ There is a lack of legal regulation regarding the limitation of CO_2 emissions in all types of motor vehicles used in the agricultural sector.

➢ Studies on creating carbon markets and gaining a share from this market are insufficient.

Measures Precautions for the Long Term

➢ In terms of supporting biofuels, there are no policies for growing products suitable for primary biofuels on vacant lands other than agricultural purposes.

➢ There are no policies regarding the production of biofuel in agricultural areas.

➢ There is a lack of legal regulation in the agricultural sector that clearly sets out emission reduction targets and comprehensively determines the measures.

➢ The current Agricultural Research Stations affiliated with the Ministry do not provide research, development and problems related to local problems such as climate change and greenhouse gas emissions to farmers.

- A certain percentage of farmer supports should be allocated for research studies.
- Areas that are out of use, such as natural meadows, should be used for the cultivation of oil plants such as jajoba.
- There are no studies on reforestation of unused areas such as stream banks in agricultural areas. There are no efforts to plant lands that are used for agricultural purposes but are below the economic value threshold with pasture or oil crops such as olives.
- Large maquis areas should be reclaimed to increase their sink capacity, and suitable areas should be used for the cultivation of oil plants such as olives, considering biological diversity.
- Studies on the completion of carbon markets and trade are lacking.

MATERIALS AND METHODS

Tillage and Irrigation Methods

Soil tillage and irrigation methods to be applied for second crop corn production are given in Table 1. Experiments will be set up according to the randomized block trial design with two replications. Corn seeds will be planted with a planter at a depth of 4-5 cm in the seed bed prepared with row spacing of 70 cm, row length of 5 m and row width of 20 cm.

The main components that passively save energy in a solar powered drip irrigation system are the energy-saving electric motor due to the low-pressure requirement, high-efficiency photovoltaic (PV) modules and the drip irrigation system. High efficiency electric motors and variable speed irrigation pumps will be used in this research. The electricity required for electric motors will be met from solar radiation with micro inverter PV modules. In this system, the use of energy-saving equipment and installations within the scope of the passive method will provide energy savings of 10-15%.

Table 1. Soil tillage and irrigation methods for second crop corn production

Methods	Soil Tillage	Irrigation
Traditional method	Tillage once with a rotavator at a depth of 20 cm Tillage once with a cultivator at a depth of 10 cm Pulling a worshiper 2 times	Flood irrigation
Water and energy saving method 1	Tillage once with a combination of rotavator and disc harrow Pulling a worshiper 2 times	Solar powered drip irrigation
Water and energy saving method 2	Tillage once with a disc harrow at a depth of 20 cm Tillage once with a spring harrow Pulling a worshiper 2 times	Solar powered drip irrigation

Calculation of CO_2, CH_4 and N_2O Emission related to Fuel Consumption

CO_2 emissions (kg CO_2/ha) related to diesel fuel and engine oil consumption per unit production area (ha) by the tractor used during corn production operations will be determined as follows:

$$CO_2 = FC \times LHV \times EF_{CO2} \quad (1)$$

where:
- CO_2 is CO_2 emissions related to fuel consumption (kg CO_2/ha),
- FC- fuel consumption (L/ha),
- LHV is lower heating value of diesel (37.1 MJ/L) and engine oil (38.2 MJ/L),
- EF_{CO2} is CO_2 emission factor for diesel and engine oil (0.07401 kg CO_2/MJ).

Methane (CH_4) emissions in corn production will be calculated as follows:

$$CH_4 = (SEV \times EF_{CH4}) \quad (2)$$

where:
- SEV is the specific energy value of diesel fuel consumed per unit grain product (MJ/kg),
- EF_{CH4} is CH_4 emission factor for diesel fuel (0.0000039 kg CH_4/MJ).

Nitrous oxide (N_2O) emissions in corn production will be calculated as follows:

$$N_2O = (SEV \times EF_{N2O}) \quad (3)$$

where:
- EF_{N2O} is N_2O emission factor for diesel fuel (0.0000039 kg N_2O/MJ).

CO_2 Equivalent Emissions related to Fuel Energy and Water Consumption

The total CO_2-equivalent emissions (CO_2-eq) as a result of diesel fuel consumption in corn production will be determined by multiplying the CO_2, CH_4 and N_2O emission amounts with the global warming potentials (GWP) for these emissions for the 100-year period as follows:

$$CO_2\text{-}eq_{energy} = (CO_2 \times 1) + (CH_4 \times 28) + (N_2O \times 265) \quad (4)$$

The total $CO_{2\text{-eq}}$ emissions resulting from water consumption in corn production will be determined as follows:

$$CO_2\text{-}eq_{water} = (WC \times EF_{CO2\text{-}eq}) \quad (5)$$

where:
- WC is the amount of water consumed per unit grain product (L/kg),
- $EF_{CO2\text{-}eq}$ is $CO_{2\text{-eq}}$ emission factor per unit (L) of water consumption (0.000344 kg $CO_{2\text{-eq}}$/L) (DEFRA, 2022).

Determination of Carbon Footprint related to Energy and Water Consumption

The carbon footprint related to energy consumption (CFP_{Energy}) can be defined as follows

$$CFP_{energy} = \frac{CO2-eq_{energy}}{M_{corn}} \quad (6)$$

where:
- CFP_{Energy} is the carbon footprint (kg $CO_{2\text{-eq}}$/kg_{corn}) related to dfuel energy (electricity+Diesel) consumption,
- M_{corn} is mass of grain corn (kg).

Similarly, the carbon footprint related to water consumption (CFP_{water}) can be defined as follows:

$$CFP_{water} = \frac{CO2-eq_{water}}{M_{corn}} \quad (7)$$

CONCLUSIONS

Global warming and the resulting climate change problem is a very important environmental problem that covers the whole world and affects all countries. Today, developed or developing countries give priority to using renewable energy sources and implementing energy saving in all production sectors.

In this study, it was aimed to determine the GHGs emissions resulting from energy and water consumption for the decarbonization of second crop grain corn production in Adana province and to develop strategies to reduce the carbon footprint. The unique value of this research is that in the production of the second product, the details of which are given in the method section, a total of three different applications will be carried out, including the traditional method and two different applications that save energy and water.

Sustainability is defined as the preservation and management of the foundations of institutional changes, technological trends and resources with the aim of continuously meeting and satisfying human needs in present and future generations. In achieving ultimate success in a project, it is important that the results of the project are sustainable. The project is designed to strengthen capacity in evaluating energy consumption in corn production. The main driving force (tool) here is to develop a strategy for studies on technological issues.

A decision support system is needed in order to realize variable rate practices in crop production management. In addition, sensing, monitoring, control and data transfer systems are technologies required for precision agriculture applications.

Variable rate irrigation is to be integrated into irrigation processes at all stages of the agricultural production cycle, using different variables such as soil moisture, effective precipitation and crop evapotranspiration to determine the optimum amount of water and ensure accurate irrigation with climate, weather forecasts and real-time weather data.

The GHGs emissions resulting from energy consumption can be reduced through the development of alternative energy projects such as solar and wind energy, which are renewable sources.

Economic supports paid by the government for the agricultural sector are an important resource that can be used to reduce GHG emissions. Agricultural insurance supports are important for protecting producers in the fight against climate change. However, it is not a tool that can be used directly to reduce greenhouse gas emissions. Organic production support is an important support that can be used to reduce greenhouse gas emissions. It is important not to use chemical fertilizers and chemical pesticides in organic cultivation. In addition, agricultural basin support is one of the most important supports that can be used in greenhouse gas reductions. Because, with this policy, the right product will be produced in the right quantities in the right basins. In this way, less chemicals will be used, and natural resources will be protected. In general, a resource can be created by supporting good agricultural practices and environmentally friendly production and branding these products.

In order to continue such studies, it should be aimed to minimize the use of smart irrigation systems with sustainable water use in today's world, where the increasing effects of global climate change are experienced globally and the negative effects of drought in the agriculture and food value chain have reached serious levels. In order to increase productivity in agriculture and create a positive impact on the food value chain, protecting and improving plant and soil health should be the main priorities of future studies. Collaboration should be ensured between universities, private sector and government institutions, and joint work should be carried out on research and development projects on relevant technologies.

ACKNOWLEDGEMENTS

This project is supported by Cukurova University Scientific Research Projects Unit with the protocol of FBA-2023-16357.

REFERENCES

Ashraf, M.N., Mahmood, M.H., Sultan, M., Shamshiri, R.R., Ibrahim, S.M. (2021). Investigation of Energy Consumption and Associated CO_2 Emissions for Wheat–Rice Crop Rotation Farming. *Energies, 14*, 5094. https://doi.org/10.3390/en14165094.

DEFRA (2022). Department for Environment Food & Rural Affairs of UK. Greenhouse gas reporting: Conversion factors 2022.

EEA (2023). Reduction of greenhouse gas emissions. European Environment Agency. https://www.eea.europa.eu/tr/themes/climate/intro

IPCC (1996). Intergovernmental Panel on Climate Change. Calculating CO_2 Emissions from Mobile Sources Guidance to calculation worksheets. (03/21/05) v1.3. https://www.ipcc-nggip.iges.or.jp/public/gl/invs1.html.

Öztürk, H.H. (2023a). *Energy saving and energy efficiency in agricultural production*. Birsen Publishing House, (In Turkish), pp. 523, ISBN 978-975-511-742-3, Istanbul.

Öztürk, H.H. (2023b). *Use of technology in agricultural production*. Birsen Publishing House, (In Turkish), pp. 358, ISBN 978-975-511-743-0, Istanbul.

Öztürk, H.H. (2024a). *Greenhouse gas emissions and carbon footprint management in agricultural production*. Academician Publishing House, (In Turkish), pp. 588, ISBN 978-625-399-581-2, Ankara.

Öztürk, H.H. (2024b). *Sustainable agricultural production*. Academician Publishing House, (In Turkish), pp. 506, ISBN 978-625-399-588-1, Ankara.