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ENERGY CONSUMPTION AND GREENHOUSE GAS EMISSIONS IN MECHANIZATION APPLICATIONS FOR TOMATO PRODUCTION

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Abstract

This study was aimed to determine the energy use and equivalent carbon dioxide emissions (CO_2-equivalent) in per unit production area (ha) considering the petroleum products (PU) directly used for the production of table tomatoes in open field conditions in Adana province. Energy consumption values related to diesel fuel and engine oil (PU) usage were calculated based on the quantities used for the unit area (ha) of PUs and lower energy values (MJ/L), which are an important indicator of the energy content of these products (PU). As the carbon dioxide emission (kg CO_2) related tothe use of PU, kg CO_2 values are taken into consideration depending on the energy content (MJ) of the PU. A total of 249.6 L/ha diesel fuel is consumed when using tools and machinery in tomato production. As a result of diesel fuel consumption, a total of 685.34 kg CO_2/ha CO_2 emission occurs in tomato production. As a result of engine oil consumption in open field tomato production, using tools and machinery, a total of 0.1153 kg CO_2/ha CO_2 emission occurs.

Key words: *tomato, fuel consumption, CO_2 emission.*

INTRODUCTION

The carbon dioxide (CO_2) comes first among the greenhouse gases and this effect is global. Greenhouse gases are released through both natural processes and human activities. The most important natural greenhouse gas in the atmosphere is water vapor. However, humanitarian activities increase the atmospheric concentrations of these gases, causing large amounts of greenhouse gases to be released. This situation warms the climate by increasing the greenhouse effect.

According to the data of Turkey Statistical Institute (TUIK, 2019), total greenhouse gas emissions in Turkey was determined as 496.1 million tonnes of carbon dioxide equivalent in 2016. In this period, the largest share of CO_2 emissions in total emissions was energy-related emissions with 72.8%, followed by industrial processes and product use with 12.6%, agricultural activities with 11.4% and waste with 3.3%, respectively. Total greenhouse gas emissions in 2016 as CO_2 equivalent increased by 135.4% compared to 1990. While the carbon dioxide equivalent emission per capita was calculated as 3.8 tons/person in 1990, this value was determined 6.3 tons/person in 2016. In 2016, 33.1% of total CO_2 emissions were from electricity and heat production, 86.1% was from energy, 13.6% was from industrial processes and product use, 0.3% was from agricultural activities and waste. 55.5% of methane emissions originated from agricultural activities, 25.8% from waste, 18.6% from energy and 0.03% from industrial processes and product use. Agricultural activities constituted the biggest proportion in diazo monoxide (NO_2) emissions with 77.6%. This was followed by energy with 12.1%, waste with 6.5%, and industrial processes and product use with 3.8%.

Tomato is a cultivated plant all over the world and its production and consumption continues to increase. Thanks to its unique nutritional value, that is, it contains lycopene, beta carotene and flavonoids, it is considered as a protective plant. In particular, it has gained a huge popularity in recent years due to the anti-oxidative activities and anti-cancer functions of lycopene (Raiola et al., 2014). Therefore, its production and consumption is constantly increasing. Tomatoes contain many phytochemicals, but the most well-known is lycopene. Lycopene; although it is found in carrot, watermelon, rosehip, chestnut, pink grapefruit, papaya and pink guava, even some of them are more than tomatoes, tomato is considered as the "source of lycopene" due to huge amount of its consumption within the year. Lycopene provides the conversion of ripe tomato fruit to red colour and is important (Figueiredo-Gonzalez et al., 2016). Today, there are many studies investigating the effects of lycopene, which has a strong antioxidant feature, on health. Antioxidants ensure that free radicals are neutralized, preventing cell components such as DNA, protein and lipids from being damaged by free radicals.

In this study, determining energy use and carbon dioxide emissions (CO_2) were aimed taking into consideration the consumption of petroleum products (PU; Diesel fuel and lubrication oil) used directly for unit production area (ha) in table tomato production in mechanization applications in open field conditions in Adana province.

MATERIALS AND METHODS

Determining the Number of Company to be Surveyed

The primary data of the study consisted of data collected by making face-to-face surveys with the producers of table tomatoes in Adana. A survey was conducted with a total of 125 tomato producers in 15 districts of Adana province, and the companies to be surveyed were determined by using stratified random sampling method.

The questionnaires applied consist of 2019 production year data. The sampling size was calculated by the *Neyman* method, the formula of which is given below.

$n = (\sum N_h S_h)^2 / (N^2 D^2 + \sum N^h S^2{}_h)$.........(1)

Where:

n = sample volume,
d = projected deviation,
N = total number of producers,
z = standard normal distribution value and
N_h = number of producers in the stratified,
S_h = stratified variance.
D = d/z

In determining the number of samples, it was studied with 5% deviation from the average and 95% confidence level. As a result of the calculations, the number of sample companies that should be worked was found as 123.5. In the research, the number of questionnaires applied to growers producing tomatoes in the open field is 125.

Tomato Production in Open Field in Adana Province

Soil Preparation: The impermeable layer is broken in early autumn by using subsoiler in order to break the impermeable layer called plow base 50 cm below the soil base. In the fall, 3-4 tons of well-burned barn manure is applied to the decare and a deep release is made. Before planting the seedlings, the field is plowed 20-30 cm deep and a disc harrow is passed.

Growing Seedlings: Generally, peat-perlite-vermiculite or peat-perlite-soil or mixtures such as burnt animal manure-sand-soil are used in seedling.

Seed Sowing: After soaking the seeds for 3-4 hours, 1-3 cm. planted in depth. Lightly watering is done after sowing seeds. When the soil temperature is 12-15ºC, the seeds germinate in 5-13 days.

Fertilization: In the spring, before preparing the furrow, the bottom fertilizer is given. All of the phosphorous fertilizer, one third of the others, is given as base fertilizer. The remaining fertilizers are given when the fruits begin to appear on the plants. When the fruits take the hazelnut size, magnesium nitrate (400-600 g/100 L water,) is applied at 2-3 times with an interval of 10-15 days. Top fertilizers are divided and divided into soil, after each irrigation, when the soil comes to the appropriate conditions are mixed. Generally, Ammonium sulfate, NPK compound fertilizers, Magnesium nitrate, Calcium nitrate, Zinc phosphate, Magnesium phosphate and plant growth regulators are frequently used during the production process.

Seedling Planting: Planting seedlings is done when the risk of spring frost is completely passed and the soil and air temperature reaches 12-15ºC. When seedlings are about 15-20 cm height, they are usually ready for planting. Planting is usually done about 7-8 weeks after sowing seeds. Seedlings are planted in Adana region from the end of February to the beginning of March. Following the planting, enough water is given. Together with first watering, necessary sprayings are made against root and shoot, in which close to the root, diseases. In tall tomato varieties, it is 60-80 cm between rows in pole varieties, 50-60 cm above rows, 140 cm between rows in floor varieties, 40-50 cm above rows.

Hoeing: The first hoeing is done 2 weeks after the seedlings are planted. The second hoeing is achieved 2-3 weeks after the first hoeing. In this period, when the plants reach a length of 30-35 cm, the tall tomato variety is planted together with the second hoeing in the tall varieties. Filling the root area is also done during these hoes. After the second hoe, weeds are removed, the creamy layer is broken, the soil is aerated and the moisture in the soil is preserved.

Irrigation: An average of 7-10 times watering is done in the region.

Pruning: In open field tomato cultivation, in order to obtain quality products pruning is achieved. Breaking the top shoot of the plant over two leaves of the last bunch is desired to be taken. The first unwanted shoot removal process starts and repeats every 10-15 days.

Disease and Pest Control: Early leaf blight, mildew, leaf mold, bacterial speckle, bacterial cancer and wilt, tomato mosaic virus and tomato yellow leaf curl virus are the main diseases, nematodes, wireworm, aphids, whitefly, thrips, leaf gallery flies, red spiders, mitesand other sucking insects are the main pests.

Harvest: Tomato fruits that are at harvest maturity are harvested by hand.

Diesel Fuel Amount Used in Open Field Tomato Production.

Diesel fuel quantities used in mechanization applications in tomato production in Adana province are given in Table 1.

Table 1. Amount of Diesel Fuel Used in Tomato Production in Open Field

Fuel	Applications	Amount used (kg/ha)
Diesel	Soil cultivation Toprakişleme	40.8905
	Fertilization (tractor) Gübreleme (traktör)	17.5245
	Pest control (tractor) Ziraimücadele (traktör)	35.049
	Irrigation+Fertilization+Spraying Sulama+Gübreleme+İlaçlama	114.8272
	Total	208.2912

Analytical Approach

The number and features of production processes in open field tomato production affect the energy efficiency of the production. Information on the processes applied in open tomato production was obtained through a survey conducted with the producers. Depending on the information obtained from the producers of open field tomatoes, the main production method for open tomato production in Adana province was determined. Diesel fuel and engine oil quantities, which are petroleum products (PU), which are directly used for tomato production, mechanization applications, for unit production area (ha), have been determined.

Energy related to the use of diesel fuel and engine oil (PU), depending on the quantities used in open-field tomato production per unit area (ha) of petroleum products (PP) and their lower heat values (MJ/L), which is an important indicator of the energy content of these products (PU) consumption values were calculated. The amount of energy consumed for the packaging, transportation, and distribution of these products was not taken into account in determining the energy values related to PP. As the carbon dioxide emission (kg CO_2) related to the use of PP, kg CO_2 values are taken into consideration depending on the energy content (MJ) of the PP.

Consumption of Petroleum Products

In the mechanization processes for tomato production in the open field, fuel consumption is consumed by tractors and irrigation pump engines in the use of tools and machinery.

- Diesel fuel consumption,
- Lubrication oil consumption and
- PP (Diesel fuel + lubricant oil) is considered as consumption.

The Diesel fuel and lubrication oil values per unit production area (ha) used by the tractor engine used during the tomato production processes in the open area were evaluated as total PP consumption.

$$m_{PP} = m_D + m_L \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where;

m_{PP} = Total petroleum products consumption (L/ha),
m_D = Diesel fuel consumption (L/ha) and
m_L = Engine oil consumption (L/ha).

Hourly oil consumption of the tractor engine, which is used for mechanization processes in tomato production in the open field, has been determined depending on the rated power of the tractor. In order to estimate hourly engine oil consumption in diesel fuel tractor engines, the following linear equation, which is dependent on Engine Rated Power (P_e) and specified in ASABE Standard D497.7 Section 3.4 (2011), is used as a reference model.

m_L=0.00059×P_e+0.02169.............…..…......(3)

Cancante et al. (2017) using the MINITAB 17.0™ data processing software, the coefficients specified in the linear regression (LRA) and variance analysis (ANOVA) and equation (3.3) are as follows:

m_L=0.000239×P_e+0.00989…......................(4)

Where;

m_L = Hourly oil consumption of the tractor engine (L/h) and

P_e = The tractor's rated power (kW).

The *Pearson correlation coefficient* for the variables in Equation (4) is r = 0.90 (p <0.05). In the developed model, the standard errors of the constant term and the linear coefficient are 1.50 10^{-3} L/h and 9.0 10^{-6} kW, respectively.

Consumption of Petroleum Products Energy

Total petroleum products energy consumption in the process of tomato production in the open field, consumed by the tractor and irrigation pump engines in the use of tools and machinery;

- Energy consumption related to diesel fuel consumption,
- Energy consumption related to lubrication oil consumption and
- It has been taken into consideration as the total energy consumption of PP (Diesel fuel + Lubrication oil) consumption.

The PP energy consumption (EC_{PP}, MJ/ha) related to diesel fuel and engine oil consumption consumed per unit production area (ha) by tractor and irrigation pump engines used during the tomato production processes in the open area is determined as follows.

EC_{PU}= EC_D+EC_L…………..…..................(5)

Where:

ET_{PP} = Total energy consumption for PP (MJ/ha),

EC_D = Energy consumption related to Diesel fuel (L/ha) and

EC_L = Energy consumption related to lubrication oil (L/ha).

Diesel fuel energy consumption (EC_D, MJ/ha) for diesel fuel consumption per unit production area (ha) has been determined by tractor and irrigation pump engines used during open field tomato production processes as follows.

EC_D=m_D×LHV_D..........……...………...….(6)

Where:

EC_D = Energy consumption related to Diesel fuel (MJ/ha),

m_D = Diesel fuel consumption (L/ha) and

LHV_D = The lower heating value of Diesel (MJ/L).

The lower heating value of diesel fuel consumed during agricultural production with agricultural tools and machinery was taken into account as LHV_D = 37.1 MJ/L (Table 2) (IPCC, 1996).

The lubrication oil energy (EC_L, MJ/ha) related to lubrication oil consumption per unit production area (ha) has been determined by tractor and irrigation pump engines used during the mechanization processes in open tomato production as follows.

EC_L=m_L× LHV_L..(7)

Where:

EC_L = Energy consumption related to lubrication oil (MJ/ha),

M_L = Lubrication oil consumption (L/ha) and

LHV_L = The lower heating value of lubrication oil (MJ/L).

The lower heating value of the engine oil consumed during agricultural production with agricultural tools and machinery was taken into account as LHV_L = 38.2 MJ/L (Table 2) (IPCC, 1996).

CO_2 Emission Regarding Petroleum Consumption

Carbon dioxide (CO_2) emission during the mechanization processes in tomato production, consumed during the use of tools and machinery;

- CO_2 emission related to diesel fuel consumption,

- CO_2 emissions related to engine oil consumption and
- It has been taken into account as the total CO_2 emission of PP (Diesel fuel + Lubrication oil) consumption.

CO_2 emissions from all motor vehicles burning fossil fuels can be calculated taking into account the amount of fuel consumed and the distance travelled. In the method of calculating CO_2 emissions taking into account the amount of fuel consumed, the value of fuel consumption is multiplied by the CO_2 emission factor for each type of fuel. This emission factor is developed depending on the heat value of the fuel and the carbon fraction oxidized in the fuel and the carbon content. This approach is defined as the fuel-based CO_2 emission calculation method as it uses average fuel consumption data. The fuel consumption-based approach can be applied taking into account vehicle effectiveness data and fuel economy factors that enable the calculation of fuel consumption. In calculating emissions using the distance-based method, distance-based emission factors are taken into account. The fuel-based CO_2 emission calculation method is the preferred approach, since data on the fuel consumed is generally more reliable. However, since the uncertainty level in CO_2 estimates can be quite high, the distance-based method should be used as a last solution (IPCC, 1996).

Taking into consideration the lubrication oil consumption value of the tractor engine, CO_2 emissions related to oil consumption can also be calculated. The values given in Table 2 are used for the heat values of Diesel fuel and lubrication oil and CO_2 emission factors depending on the type of fuel.

Table 2. Heating Values and CO_2 Emission Factors (IPCC, 1996)

Fuel	**Lower heating value (MJ/L)**	**CO_2 emission factor (kg CO_2/MJ)**
Diesel fuel	37.1	0.07401
Lubrication oil	38.2	0.07328

In the calculations made to determine the CO_2 emissions released regarding the use of PP as a result of open field tomato production, the fuel-based CO_2 emission calculation method proposed in the Intergovernmental Climate Change Panel has been taken into consideration (IPCC, 1996). The proposed approach to calculate CO_2 emissions based on fuel consumption is summarized in equations (10) and (11).

The total CO_2 emission per unit production area (ha) of PP consumption (TCO_2E_{PP}, kgCO_2/ha) has been determined by the tools and machines used during open tomato production.

$$TCO_2E_{PP}=CO_2E_D+CO_2E_L \quad (8)$$

Where:

TCO_2E_{PP} = Total CO_2 emission related to PP consumption (kg CO_2/ha),
CO_2E_D = CO_2 emissions related to Diesel fuel consumption (kg CO_2/ha) and
CO_2E_L = CO_2 emission related to lubrication oil consumption (kg CO_2/ha).

CO_2 emission (CO_2E_D, kg CO_2/ha) for Diesel fuel consumption per unit production area (ha) was determined by agricultural tools and machinery used during open tomato production processes as follows.

$$CO_2E_D=m_D\times LHV_D\times EF_D \quad (9)$$

Where:

CO_2E_D = CO_2 emissions related to Diesel fuel consumption (kg CO_2/ha),
m_D = Diesel consumption (L/ha),
LHV_D = Lower heating value of Diesel (37.1 MJ/L) and
EF_D = CO_2 emission factor for Diesel fuel (0.07401 kg CO_2/MJ).

The CO_2 emission factor of Diesel fuel consumed during agricultural production with agricultural tools and machinery is taken into account as EF_D = 0.07401 kgCO_2/MJ (Table 2) (IPCC, 1996).

CO_2 emissions (CO_2E_L, kgCO_2/ha) for lubricant oil consumption per unit production area (ha) was determined by agricultural tools and machinery used during open tomato production processes.

$$CO_2E_L=m_L\times LHV_L\times EF_L \quad (10)$$

Where:

CO_2E_L = CO_2 emission related to lubrication oil consumption (kg CO_2/ha),
m_L = Lubrication oil consumption (L/ha),

LHV_L = Lower heating value of lubrication oil (37.1 MJ/L) and
EF_L = CO_2 emission factor for lubrication oil (0.07401 kg CO_2/MJ).

The CO_2 emission factor of the lubrication oil consumed during the production processes in the field with agricultural tools and machinery is taken into account as EF_L = 0.07328 kg CO_2/MJ (Table 2) (IPCC, 1996).

RESULTS AND DISCUSSIONS

Diesel Fuel Consumption

Diesel fuel consumption values in the use of tools and machinery during the mechanization processes in open-field tomato production in Adana province are given in Figure 1. Diesel fuel consumption values given in Figure 1 indicate the average values of diesel fuel consumption values determined from the districts of Adana province. It is seen that diesel fuel consumption values are in parallel with the change in the usage time of the tools and machines used in the open tomato production process and the loading rates of the tractor engine. The highest diesel fuel consumption is in pump irrigation applications, which includes irrigation + fertilization + spraying with 137.6 L per unit area (ha). Soil cultivation applications take the second place in diesel fuel consumption with 49 L/ha. Diesel fuel consumption in open tomato production is 42 L / ha in tractor and plant protection products (PPP) applications and 21 L/ha in PPP applications. A total of 249.6 L/ha diesel fuel is consumed when using tools and machinery in tomato production.

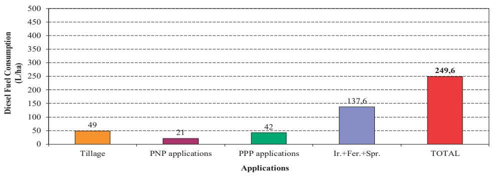

Figure 1. Change of Diesel Fuel Consumption in Open Field Tomato Production (Own findings)

Diesel Fuel Energy Consumption

Diesel fuel energy consumption values in the use of tools and machinery during open field tomato production processes in Adana province are given in Figure 2. The highest diesel fuel energy consumption is determined in pump irrigation applications, which includes irrigation + fertilization + spraying operations with 5104.96 MJ per unit area (ha). Soil cultivation applications take the second place in diesel fuel energy consumption with 1817.9 MJ/ha.

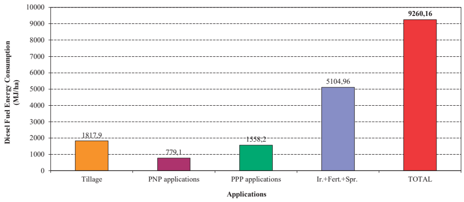

Figure 2. The Change of Diesel Fuel Energy Consumption in Open Tomato Production (Own findings)

Diesel fuel energy consumption in open field tomato production is 1558.2 MJ/ha in tractor and BMU applications and 779.1 MJ/ha in BBU applications. A total of 9260.16 MJ/ha diesel fuel energy is consumed when using tools and machinery in tomato production.

CO_2 Emission Regarding Diesel Fuel Consumption

CO_2 emission values resulting from Diesel fuel consumption in the use of tools and machinery during the mechanization processes in open field tomato production in Adana province are given in Figure 3. As a result of the highest diesel fuel consumption, the maximum CO_2 emission per unit area (ha) is realized in pump irrigation applications, which includes irrigation + fertilization + spraying processes with a value of 377.82 kgCO_2. Soil cultivation practices take the second place in CO_2 emission with the value of 134.54 kg CO_2/ha.

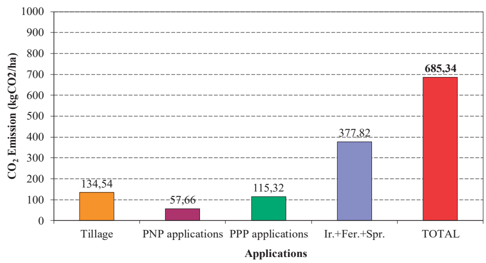

Figure 3. CO_2 Emission Regarding Diesel Fuel Consumption in Open Field Tomato Production (Own findings)

As a result of diesel fuel consumption in open tomato production, 115.32 kg CO_2/ha CO_2 emission occurs in tractor and PPP applications and 57.66 kg CO_2/ha CO_2 in plant nutrition products (PBU) applications. As a result of diesel fuel consumption, a total of 685.34 kg CO_2/ha CO_2 emission occurs in open field tomato production.

Lubrication Oil Consumption

The lubrication oil consumption values of the engines that run the tractor and irrigation pumps in the process of tomato production in the open field are given in Figure 4. The lubrication oil consumption values given in Figure 4 indicate the average values of lubrication oil consumption values determined from the districts of Adana province. It is observed that the lubrication oil consumption values are in parallel with the usage time of the tools and machines used in the open tomato production process and the loading rates of the tractor engine, as in the Diesel fuel consumption values.

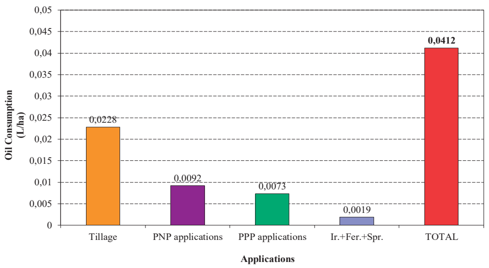

Figure 4. Change of Average Oil Consumption in Open Field Tomato Production (Own findings)

The highest oil consumption is realized in soil cultivation applications with 0.0228 L per unit area (ha). PBP applications take the second place in oil consumption with a value of 0.0092 L/ha. In tomato production in open air, lubrication oil consumption in BBP applications is 0.0073 L/ha. A total of 0.0412 L/ha of engine oil is consumed when using tools and machinery in tomato production.

Energy Consumption Related to Lubrication Oil Consumption

Lubrication oil energy consumption values in the use of tools and machinery during open tomato production processes in Adana province are given in Figure 5. The highest lubrication oil energy consumption is determined in soil cultivation applications with 0.87 MJ per unit area (ha). PBP applications take the second place in lubrication oil energy consumption with 0.35 MJ/ha.

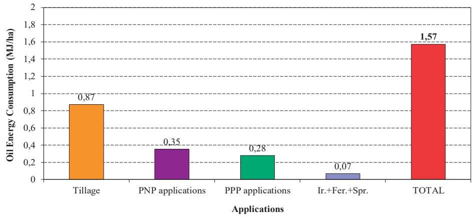

Figure 5. The Change of Lubrication Oil Energy Consumption in Open Field Tomato Production (Own findings)

Lubrication oil energy consumption in open tomato production is 0.28 MJ/ha in tractor and PPP applications. A total of 1.57 MJ/ha engine oil energy is consumed when using tools and machinery in tomato production.

CO_2 Emission Regarding Engine Oil Consumption

CO_2 emission values that occur as a result of engine oil consumption in the process of tomato production in open field in Adana province are given in Figure 6. As a result of maximum engine oil consumption, the highest CO_2 emission per unit area (ha) is realized in tillage applications with a value of 0.0638 kg CO_2. The second place in CO_2 emission is PBP applications with the value of 0.0258 kg CO_2/ha.

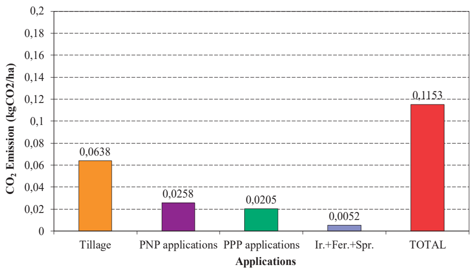

Figure 6. CO_2 Emission related to Engine Oil Consumption in Open Field Tomato Production (Own findings)

As a result of engine oil consumption in open field tomato production, 0.0205 kgCO_2/ha CO_2

emission occurs in tractor and BKU applications. As a result of engine oil consumption in open tomato production, using tools and machinery, a total of 0.1153 kg CO_2/ha CO_2 emission occurs.

CONCLUSIONS

In open field tomato production; 249.6 L/ha diesel fuel and 0.0412 L/ha lubrication oil are consumed in the use of tools and machinery.

In open field tomato production; a total of 9260.16 MJ/ha diesel fuel energy and 1.57 MJ/ha lubrication oil energy are consumed in the use of tools and machinery. In open field tomato production; As a result of diesel fuel consumption, a total of 685.34 kg CO_2/ha CO_2 and 0.1153 kg CO_2/ha CO_2 emission occur as a result of engine oil consumption. To produce 1 kg of fresh tomatoes in open field tomato production, a total of 2.625 g of Diesel fuel and engine oil are consumed in mechanization applications. As a result of Diesel fuel and engine oil consumption to produce 1 kg of fresh tomatoes, 115.77 kJ energy consumption 8.568 kg CO_2 emission occurs. Technologies with high energy efficiency should be used for the mechanization infrastructure of the companies. Tools/machines with a capacity suitable for the power supply should be used. Necessary power optimization for the companies should be provided. For example, operations that require less power should not be performed with larger powerful tractors. Agricultural tools/machines should be operated at full load and efficiently. With the agricultural tools/machinery used in open field tomato production processes, fuel consumption during the work should be carefully monitored. Measures to reduce fuel consumption should be taken by evaluating the power requirements of the machines used.

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