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POWER AND ENERGY REQUIREMENTS OF AGRICULTURAL MACHINERY DRIVEN BY TRACTOR USED ON GREENHOUSE VEGETABLE PRODUCTION IN TURKEY

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ABSTRACT Power and energy requirement data is often used in machinery management. Farm system models often require power data to predict machine performance and fuel requirement. As seen in previous researches, many studies on the subject of power and energy requirements mostly concentrated on field crops production. However, the investigations related to energy use in greenhouse vegetable production are very limited. Turkey is an important state of protected cultivation in the Mediterranean area. This research was carried out in Antalya province which is in the centre of Turkey's greenhouse vegetable production. In greenhouse areas, mostly vegetables are cultivated in soil culture. In this research, power and energy requirements for agricultural machinery used for greenhouse vegetable production were determined and compared with the machinery used for field crop productions. In the production, some agricultural machinery is used in tillage and transportation operations like mouldboard plough, chisel, cultivator, rotary tiller and trailer driven by tractor. In greenhouse experiments, basic operational data are measured by a computer based data acquisition system. According to the results, the forward speeds of tillage machines, determined between 1.6 and 2.0 km/h, were lower than that of farm machinery used in field crops. Total power requirements of tillage machines were between 7.1-14.5 kW and that of trailer was 18.4 kW. Energy requirement of the rotary tiller (80.6 kW–h/ha) was greater than for the other tillage machines. The energy requirement values of moldboard plough, chisel and cultivator were 46.9, 38.2 and 30.9 kW-h/ha, respectively. Energy requirement per material mass during transportation operation was calculated as 0.53 kW-h/t.

Keywords: Greenhouse production, power and energy, agricultural machinery

INTRODUCTION Greenhouse can be described as constructions in which the growing conditions are regulated artificially in order to cultivate crops throughout the year (Deviren 1992). Greenhouse cultivation is widespread in Mediterranean coastline countries. Similarly, Turkey's Mediterranean coastline is an important greenhouse centre in the region because of available ecological conditions. Beside the Mediterranean coastline, greenhouse practices are also expanded to Agean, Marmara, Blacksea and South East regions (Kendirli 2007). Turkey has 27084 ha greenhouse area, totally.

Considering the cover material of the greenhouse areas, glasshouse and plastichouse constitute 28% and 72% of the total area, respectively. The main crops cultivated in the greenhouses are vegetables (95%), ornamental crops, seedlings and fruits (TUIK, 2008).

In greenhouse areas, traditional cultivation methods are practiced generally on the soil culture. Hence, some agricultural machines powered by tractor are used for tillage operations which are realized before transplanting and after harvest of the crops. In addition, some farmers transported their harvested crops from greenhouse to wholesale food markets with trailer pulled by tractor. Also, the transportation operations were realized on different vehicles and some farmers use trailer for this operation.

Power requirement data is often used in machinery management. Farm managers and farm management consultants use power data to match tractors and implements for efficient and cost-effective operations. Improperly matched implements reduce the machine capacity, excess machine wear, breakdowns etc. Power data can also be used to determine engine load and fuel consumption for an individual operation. Farm system models often require power data to predict machine performance and fuel requirement. Accurate information on power requirements is necessary to produce valid models (Rotz and Muhtar, 1992).

Many agricultural machines provide a functional load for the tractor's PTO drive and rolling resistance load for its drawbar. In agriculture, the product of power and time per area has utility and is the energy unit used, enabling a manager to estimate power requirements to obtain certain capacity, or conversely, given the power available to estimate the capacity. The common unit for field work is kW-h/ha. The most important point about energy requirement is that they are essentially constant regardless of the size of tractor and implement (Hunt, 1973).

It is known that studies on the subject of power and energy requirement, mostly concentrated on open field machinery, have been conducted on agricultural production. Barut et al. (1995) determined some working parameters of small tractor-plough combination in greenhouses soil. Some literature values are summarized in Table 1. However, the investigations related to tillage machines used in greenhouse cultivation are very limited. More research is needed to document the power and energy requirements of resources in greenhouse production.

Table 1. Energy requirement reported for some tillage machines in previous researches (kW-h/ha)

Machines	Hunt (1973)	Bowers (1975), Hunt (1968)*	Butterworth ve Nix (1983)*, **	Işık (1988)+	Anonymous (2000)
Moldboard plough	21.8-45.4	8.7-40.6	18.6-61.5	54.3	-
Chisel	8.0-36.4	29.5	18.1-40.3	24.2	-
Cultivator	2.4-11.8	14.8	10.0	23.6	-
Rotary cultivator	25.4-50.1	-	30.3-55.6	-	43.1-65.41

* referred from Evcim (1990)

** field efficiency was not taken into consideration

\+ rolling resistance was taken into consideration

The aim of this study was to obtain the power and energy requirements of agricultural machinery driven by tractor used on greenhouse production. In this scope, draft force, torque, ground speed and wheel slip were measured. Then, values for drawbar, PTO and total power, and area and yield capacity were calculated.

MATERIAL AND METHODS The experiments done to measure draft and torque values of the machines were carried out in a greenhouse located in Akdeniz University, Antalya, Turkey. Soil moisture of the greenhouse was 21% during the experiments. Some properties of the greenhouse, its soil structure and properties of five different agricultural machines used in this research were presented in Table 2, 3 and 4, respectively.

Table 2. Some properties of the greenhouse used to conduct experiments.

Type	Wide span
Covering material	Glass
Construction material	Iron
Effective floor size, m	18×55
Effective area, (m^2)	990
Side wall height (m)	2.0
Central height (m)	5.5
Ventilation type	Natural

Table 3. Some properties of the greenhouse soil.

Soil depth (cm)	0-30
Specific mass (g/cm^3)	1.22
Organic matter content (%)	2.70
pH	7.79
Texture,	Clay soil
- % sand	16.0
- % Silt	26.8
- % clay	57.2

Table 4. Some properties of agricultural machines.

Machines	Type	Working width (m)
Moldboard plough	5 plough	1.5
Chisel	7 tine	2.0
Cultivator	9 tine	2.0
Rotary cultivator	42 knife, L type	1.8
Trailer	4 t	-

The implement force and torque variables were measured by a computer based data acquisition system. This measuring system consisted of a dynamometer (HBM, 50 kN), a torquemeter (Digitech, 2000 Nm), a data logger, a laptop PC and a connection frame. Implement force and PTO torque data were recorded on a data logger in every second. Implement forces, torque and slippage values of the agricultural machines were determined by evaluation of measurement carried out with three replications on 20 m long plots.

Two tractors, a Steyr 8073 and Steyr 8056, were used for measuring the implement force and the PTO torque in the greenhouse. The force dynamometer was mounted between the tractors. The torquemeter was installed between the second tractor's PTO shaft line and attached machine. The second tractor's drive gear was always disengaged and this tractor was used only for driving the PTO. The first tractor was only used for pulling. The implement force was obtained by subtracting the rolling resistance of the second tractor from the force dynamometer value (Hoki et al.,1988).

PTO torque was measured by using a torquemeter and PTO revolution was obtained by using a digital tachometer. Working speed was estimated by measuring time and plot length for each experimental plot. Wheel slip was determined by measuring the revolutions of driven wheels of tractor under actual load and no-load operations (ASAE, 2001a). Drawbar power was converted into equivalent PTO power. A ratio of drawbar power to PTO power was used as 72% reported in ASAE (2001b) paper under firm soil conditions. Moldboard plough and chisel were worked on no till and cultivator and rotary tiller were worked on tilled soil conditions. In calculating drawbar and PTO power, standard equations were used. Area capacity values of the machines were calculated by considering the values of working speed, working width, and area efficiency (Isık, 1988; ASAE, 2001a; ASAE 2001b). Area efficiency was determined according to turning time of field heads, breakdowns with a short time and other time loses. Energy requirement was estimated from the total power divided by the effective area capacity.

RESULTS AND DISCUSSION

Working speed and area efficiency values of the machines used in greenhouse vegetable cultivation Some working parameters of the agricultural machines used in the greenhouse vegetable cultivation were shown in Table 5.

Table 5. Some working paramaters values of the agricultural machines

Machines	Working width	Working time ($h/1000\ m^2$)		Area Efficiency	Working speed	Effective area capacity	
	(m)	Net	Total	(decimal)	(km/h)	($1000\ m^2/h$)	(ha/h)
Moldboard plough	1.5	0.52	0.94	0.55	1.9	1.6	0.16
Chisel	2.0	0.29	0.48	0.60	1.8	2.2	0.22
Cultivator	2.0	0.26	0.45	0.58	2.0	2.5	0.23
Rotary cultivator	1.8	0.40	0.65	0.62	1.6	1.7	0.18

As seen in Table 5, area efficiency and working speed values with working tillage machines were changed in the ranges of 0.55-0.62 and 1.6-2.0 km/h, respectively. Total time requirements per working area ($1000\ m^2$) were in the range of 0.29-0.52 h. The calculated effective area capacity values of the machines were between 0.16 and 0.23 ha/h. It was obtained that moldboard plough required maximum operation time for per area. The machine had the minimum area efficiency and area capacity values. Working speed and area efficiency values of the machines were very close to each other. For a general definition, it can be said that working speed values were in the range of 1.5-2.0 km/h and area efficiency values was 0.6 (60%) for tillage machines used in greenhouse cultivation.

A research was carried out by Barut et al. (1995) in Antalya region of Turkey. In the research conducted in a greenhouse, small mouldboard plough was worked by tractor with one axle. Average forward speed, area efficiency and area capacity were found between 1.8-2.3 km/h, 0.76-79 and 0.033-0.035 ha/h, respectively. The forward speed values were close to the values indicated in Table 5. Otherwise, area efficiencies were higher and area capacities were lower than the values determined in this research.

The ranges of working speed and field efficiency values for moldboard plough, chisel and cultivator in open field crop cultivation were reported as 5-10 km/h and 0.70-0.90 (Işık, 1988; Darga, 1989; Evcim, 1990; Witney, 1996; ASAE 2001a). These values were indicated between 2.0-7.0 km/h and 0.70-0.90 ranges for rotary tiller. For machines with similar properties, related values found in greenhouse were lower than those reported in field condition. In greenhouses, desired working speed values can not be realized due to smaller distance. It can be said that some special parameters such as smaller production sizes, difficulty of turning operations etc. causes lower working speed and area efficiency values related on working greenhouses.

Findings related to power and energy requirements of the agricultural machines The operation variables, and power and energy requirements for agricultural machines were given in Table 6 and Table 7.

Table 6. Working speed, working depth, rolling resistance, draft force and torque values of agricultural machines

Machines	Working speed (km/h)	Working depth (m)	Rolling resistance (kN)	Total draft force		Torque (Nm)
				(kN)	(kN/m)	
Moldboard plough	1.9	0.20	0.9	9.5	6.3	-
Chisel	1.8	0.32	0.9	10.9	5.5	-
Cultivator	2.0	0.19	1.0	7.6	3.8	-
Rotary cultivator	1.6	0.09	1.1	1.5	0.8	226
Trailer	10.0	-	1.3	4.9	1.4*	-

*unit draft force for trailer; kN/t

Table 7. Wheel slip, tractive efficiency, energy requirement and loading ratio values of the agricultural machines

Machinery	Wheel slip (%)	Tractive efficiency (decimal)	Total power (kW)	Energy requirement (kW-h/ha)	Loading ratio (decimal)
Moldboard plough	18.1	0.70	7.5	46.9	0.23
Chisel	21.3	0.68	8.4	38.2	0.25
Cultivator	14.6	0.62	7.1	30.9	0.21
Rotary cultivator	5.8	0.41	14.5	80.6	0.44
Trailer	5.3	0.77	18.4	0.53*	0.55

*unit of energy requirement for trailer; kW-h/t-km

Table 6 shows that working depths were 0.20, 0.32, 0.19 and 0.09 m for moldboard plough, chisel, cultivator and rotary cultivator, respectively. Total draft force values were ranged between 1.5-10.9 kN depending on machine properties and their operation. Average draft force per working width varied from 0.8 to 6.3 kN/m for tillage machines and torque value for rotary tiller powered by PTO was determined as 226 Nm. For trailer, working speed and total draft force values were measured as 10.0 and 4.9 kN, respectively.

In tillage machines, average wheel slip and tractive efficiency varied from 5.8 to 21.3% and 0.41 to 0.70, respectively. Tractive efficiency values of moldbaord plough and chisel operated on no till were higher than cultivator and rotary tiller operated on tilled soil. Working on tilled soil together with lower wheel slip value caused having minimum tractive efficiency of rotary tiller. Wheel slip and tractive efficiency values of trailer were found as 5.3% and 0.55, respectively.

Total power requirements of tillage machines were between 7.1-14.5 kW. Energy requirement of rotary tiller (80.6 kW–h/ha) was greater than the other tillage machines. The energy requirement values of moldboard plough, chisel and cultivator were 46.9, 38.2 and 30.9 kW-h/ha, respectively. Table 7 shows that the loading ratio values ranged from 0.21 to 0.44 for soil tillage machines. Maximum and minimum loading ratio values were determined on working with rotary tiller and cultivator, respectively. Energy requirement per mass of transporting material and loading ratio were calculated as 0.53 kW-h/t and 0.55, respectively.

As shown in Table 1 energy requirement were changed between wide limits. On working agricultural machinery many factors as working speed, soil properties, technical characteristics effects energy requirement values. The findings obtained in this research were close to high limit values reported for field conditions or higher. For example, 46.9 kWh/ha values of moldboard plough was near the high limit. However, the values of 30.9 kW-h/ha and 80.6 kW-h/ha calculated for cultivator and rotary tiller were higher than top limits reported in Table 1. It can be said that higher energy requirements for greenhouses in comparison with field conditions were caused by many variables such as different land sizes, area capacity, working conditions etc…

CONCLUSION In this research, power and energy requirements were determined for agricultural machinery powered by tractor used on greenhouses vegetable production in Turkey. Total five machines were evaluated. Investigated machines were moldboard plough, chisel, cultivator, rotary tiller and trailer. For a general definition, it can be said that working speed values were in the range of 1.5-2.0 km/h ranges and area efficiency values was 0.6 (60%) for tillage machines used in greenhouse vegetable cultivation. For machines with similar properties, related values found in greenhouse were lower than those reported in field conditions. Total power requirements of tillage machines were between 7.1-14.5 kW and that of trailer was 18.4 kW. Energy requirement of rotary tiller (80.6 kW–h/ha) was greater than the other tillage machines. The energy requirement values of moldboard plough, chisel and cultivator were 46.9, 38.2 and 30.9 kW-h/ha, respectively. Energy requirement per material mass during transportation operation was calculated as 0.53 kW-h/t. It can be said that findings of the research symbolizes to the regional properties. These data determined for greenhouse cultivation area on which it was not worked much can be used in machinery management and energy efficiency studies.

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