EVALUATION OF TILLAGE EFFICIENCY AND ENERGY REQUIREMENTS FOR FIVE METHODS OF SOIL PREPARATION IN THE SUGAR BEET CROP

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***Abstract**: Reduced tillage operations can provide soil conservation as well as significant energy savings. A seven year experiment was carried out in Central Greece in order to evaluate the energy budget in the sugar beet crop. Tested methods were: reduced tillage with a heavy cultivator or subsoiler (HC), rotary cultivator (RC), disk harrow (DH) and no-tillage (NT) compared with a conventional tillage method (CT) using plough. Compared with the (CT) method the reduced tillage methods provided energy savings but also resulted on greater yield losses. As a result, energy productivity was reduced. The results for the (HC) method however were comparable with the (CT).*

***Key words: Tillage, energy, sugar beet**.*

INTRODUCTION

Sugar beets is the 5th most important arable crop and are cultivated in Greece that cover an area of 44.200 hectares. Farmers face with a reduction of their income as the prices of the agricultural supplies raise while the new rules of GATT and CAP reduce the prices of the agricultural products. The only solution to support a viable and profitable production is to reduce production costs while retaining the productivity of the system. The productivity of a system is on an energy budget [5].

The farm agricultural machinery use is considered the main factor contributing to the total energy inputs in the agricultural system [4]. Tillage represents half of the operations carried out annually in a field. Consequently, there is potential to reduce energy inputs and production costs by reducing tillage [8,13]. In addition, reduced tillage methods promote soil conservation according to the directives of Good Agricultural Practices of the E.U. Even though a lot of work is done with other crops, such as wheat and corn, the research concerning the adaptation to reduced tillage for sugar beets are limited. Especially in Greece, no other research in sugar beet was reported. Researches carried out in Northern European countries indicate a positive response of the sugar beet crop to reduced tillage with yields being equal or slightly less than conventional tillage [9,11]

In order to investigate the energy reduction with the adoption of reduced tillage and the probable effect in crop yield, a long period experiment was established on the the University of Thessaly farm in Central Greece. The first seven years data are presented in this paper. Five tillage methods are valuated based to an energy analysis.

MATERIALS AND METHODS

1. Description of the experiment

The experimental design was split blocks with four replications. The experiment was conducted at two fields (a silty – clay: sand 9.7%, silt 41.1%, clay 49.2%, O.M. 1.26% and a clay: sand 20.1%, silt 32.7%, clay 47.1%, O.M. 1.08). At the first three years the sugar beet crop was planted in both fields according to a crop rotation with cotton and maize. In the next period it followed a rotation with wheat and maize and it was alternatively planted from one field to the other (in year 2000 both fields had a winter wheat crop). Sub-plots had dimensions 6×10 m with 12 rows of sugar beet. Five methods of tillage were tested. 1) Conventional tillage (CT) including ploughing at a depth of 25-30 cm and final preparation with a disk harrow. 2) Reduced tillage (HC) with a heavy cultivator or a subsoiler at a depth of 20-25 cm and final preparation with a disk harrow. 3) Reduced tillage with a rotary cultivator at a depth of 12-15 cm and in some of the years, final preparation with a disk harrow. 4) Reduced tillage with a disk harrow at a depth of 7-8 cm. Two to four passes were conducted according to the soil conditions each year. 5) No tillage. The method included direct drilling over existing vegetation and *glyphosate* or *paraquat* application right after. A croskill cylinder was used during the last three years in the no-till plots in order to improve seed-soil contact. Tillage operations for each year are shown in Table 1. Cultivation practices (fertilization, irrigation, seed rate e.t.c.) were the same for all the treatments according to the needs of the highest yield (Table 2). Drip irrigation was applied with pipes spread every second row of the crop. Harvest for yield estimation was done manually from two rows of 7,5 m on each plot. Samples were taken to analyse for sugar content.

Table 1. Tillage operations for each year

	CT	HC	RC	DH	NT
1997:	pl+2dh	hc+2dh	rc+2dh	4dh	
1998:	pl+2dh	hc+dh	rc+dh	2dh	
1999:	pl+2fc	ch+2fc	rc+fc	2dh+fc	
2001:	pl+2fc	ch+2fc	rc+2fc	2dh+2fc	2cc
2002:	pl+2dh+fc	hc+dh+fc	rc+fc	3dh+fc	cc
2003:	pl+rc+dh	hc+3dh	rc+dh	3dh	cc

pl = mouldboard plough, hc = heavy cultivator, ch = chisel plough, rc = rotary cultivator, dh = disk harrow, fc = field cultivator, cc = croskill cylinder

2. Determination of energy demands

A 82 kW Ford tractor was used for all field operations. A draft measuring device consisting of two metal frames joined together with six loadcells [12] was attached at the three point hitching system of the tractor. The device was attached between the tractor and the implement. For the PTO powered equipment a torque and rotating velocity measuring device were attached on the PTO. A radar attached on the tractor was also used to record forward speed. All the data were recorded on a laptop PC carried on the tractor [12]. From the above data, the real absorbed power was estimated as well as the absorbed energy for the attached implements.

After the third year of the experiment, a fuel consumption sensor was also attached on the tractor fuel supply system measuring direct fuel consumption. A normal test on the tractor engine was also carried out by applying known loads on the PTO via a tractor dynamometer device (*Froment Tractor Test Center*) and measuring the fuel consumption. From the above data it was estimated the specific fuel consumption curve. By using this curve it was also possible to estimate the equivalent PTO power ($P(EQ)_{PTO}$) during field operations and from that, tractive efficiency (TE) using the formula:

$$TE = \frac{Ptr}{P(EQ)_{PTO} - P_{PTO}} \quad (1)$$

where: P_{tr} = the real power absorbed by the implement and measured by the metal frame and loading cell device and P_{PTO} = the real PTO power absorbed by implements using the PTO and measured with the torque and roating velocity device. Coefficients of tractive efficincy for each tillage implement are presented in Table 3. These coefficients were used for the estimation of the equivalent PTO power during the first two years (using the equation 1). The specific fuel consumption curve was used to estimate the fuel consumption for these two years.

Machinery characteristics and cone index data (not presented in this work) were used to estimate motion resistance of tractor wheels during edge turns [1]. A coefficient equal with 0,95 [2] was used to convert axle power to equivalent PTO power. From the specific fuel consumption curve it was estimated again the fuel consumption. Fuel consumed during field operations and fuel consumed on edge turns was total fuel consumption in the field operations. Multiplying total fuel consumption with diesel fuel energy equivalent (38,66 MJ·l^{-1}) [4] the fuel energy inputs was estimated. Taking also into account a coefficient equal to 0,81 for shipping, refining and delivering diesel fuel the initial fuel energy was estimated. Energy for lubricants of tractor was estimated as 4% of the initial fuel energy.

Table 2. Agricultural inputs for crop production and corresponding energy values

	1997	1998	1999	2001	2002	2003	Energy[(2)] (MJ.kg^{-1})
Fertilizers (kg ha^{-1})							
N	70	140	140	130	100	115	76,6
P	140	70	70	70	100	90	16
K	300	20	70	50	0	90	12,8
Seeds (kg ha^{-1})	6	6	6	6	6	6	54,24
Herbicides (kg a.i. ha^{-1})							
Desmedipham	0,06	0,09	0,09	0,06	0,06	0,09	307,8
Phenmedipham	0,06	0,09	0,09	0,06	0,06	0,09	307,8
Ethofumesate	0,06	0,09	0,09	0,3	0,36	0,36	307,8
Metamitron	0,7	1,05	1,05	0,7	0,7	0,7	317,8
Parafinic oil	1	1,5	1,5	1	1	1	25,5
Clopyralid				0,2			289,5
Metolachlor					1,44	7,68	317,8
Haloxyphop	0,11	0,09	0,09	0,17	0,22	0,15	307,8
Glyphosate[(1)]	3,36	3,36	3,36		3,36	3,36	522,1
Paraquat[(1)]				1,2			516,3
Insecticides (kg a.i. ha^{-1})							
Methidathion	0,06						254
Fungicides (kg a.i. ha^{-1})							
Maneb	10	8	10	11,9	7,9	11,9	204,2
Irrigation (m ha)	0,56	0,52	0,52	0,47	0,44	0,42	83 397[(4)]

(1) *Glyphosate or paraquat were applied only in the NT method*

(2) *Data from Helsel, 1992 (for no refered pesticides, it was calculated the average value from the refered)*

(3) *Data from Chancellor et al, 1980*

(4) *Energy required for 1 ha m of water and calculated from equation 2*

According to the machinery weights and data presented in the literature [4], the total sequestered energy in the agricultural machinery for manufacturing, transportation and repairs was estimated. Considering the width of operation of each implement and the forward speed the machinery output was estimated and from that the sequestered energy for the implement and the tractor field work per ha. Energy of human labor was considered negligible and wasn't taken into account because of the great debate concerning the energy equivalent of human work [6].

According to the quantities used for the other inputs in the crop production (seeds, fertilizers, pesticides e.t.c.) and the corresponding energy values (Table 2) it was estimated the energy inputs. Energy inputs for irrigation were estimated from the formula:

$$DE_{ha} = \frac{EU}{EF_p \times EF_l \times EF_c} \times TDH = \frac{9,81}{0,18 \times 0,76 \times 0,91} \times 105,8 = 8339,7\,MJ\ per\ m\ ha \quad (2)$$

where DE_{ha} = is direct energy requirements per ha m, EU energy required to lift 1 ha m of water at a height of 1 m, EF_p the efficiency of power source considered equal to 0,18 [7] (a 15 hp electric motor was used for powering the pump), EF_l the efficiency of the pump considered equal to 0,76 [7], EF_c efficiency of the water distribution network (for a drip irrigation system it was considered equal to 0,91) [7] and TDH the total dynamic head which was 105,8 m. By multiplying the above value with the annual water supply to the crop m·ha (Table 2) it was estimated the energy inputs with irrigation.

Data for crop harvest was taken from the literature. The fuel energy consumed by the harvester was estimated [10], The energy of the lubricants was 4% of fuel energy [4] as well as the energy sequestered in the machine for manufacturing, transporting and repairs was estimated [4].

Energy outputs were calculated for each method of tillage from the crop yield on crystallized sugar, molasses and pulp. The high heating value of crystallized sugar was considered 16,51 MJ·kg^{-1} [10], molasses 12,65 MJ·kg^{-1} [3] and pulp 12,1 MJ·kg^{-1} [3].

RESULTS AND DISCUSSION

Data of the real absorbed energy with each implement are presented in Table 3. The data are the average values from the six years measurements. As it can be seen, the mouldboard plough had the greater energy consumption through traction, followed by the chisel plough and the heavy cultivator. These implements however worked on the greater depth. The rotary cultivator absorbed little energy from traction but had great energy demands through the PTO. As a result, it presented the greater energy consumption. Combined with a much shallower working depth, the implement was proved to be the most intensive (in terms of energy spent in the soil per cultivated volume). The disk harrow and the field cultivator presented the lower energy demands but also had the shallower tillage depth. Considering the equivalent PTO power (Table 3) an apparent advantage for the rotary cultivator can be seen due to the greater efficiency of power transmission through the PTO. Thus the rotary cultivator had lower energy demands than moulboard and chisel plough and greater demands than the heavy cultivator. By examing the total energy consumed (the energy of fuel and lubricants as well as the reduction of the machinery sequestered energy) it can be noticed that the moalboard plough was the most energy consuming implement. With the chisel plough, energy savings of 18% were achieved. The rotary cultivator provided savings of 28% and the heavy cultivator savings of 45%. The disk harrow and the field cultivator were 86-87% less energy consuming.

Table 3. Energy consumption with the tillage implements

	Absorbed Energy on traction	Absorbed Energy on the PTO (MJ ha^{-1})	Energy consumed on turning edges	C_t	Equivalent PTO energy (MJ ha^{-1})	Fuel and lubricants energy (MJ ha^{-1})	Reduction of machinery sequestered energy (MJ ha^{-1})	Total energy (MJ ha^{-1})
Plough	189		9	0,53	367	1930	225	2155
Heavy cultivator	111		5	0,53	216	1085	105	1190
Chisel plough	162		7	0,52	318	1594	184	1778
Rotary cultivator	22	197	5	0,49	266	1407	147	1554
Disk harrow	17		3	0,43	43	242	59	301
Field cultivator	19		2	0,43	47	247	36	283
Crosskill cylinder	0,3		2	0,07	7	37	30	67

C_t = coefficients of traction efficiency

In Table 4, it is calculated the total energy inputs for each method of tillage. Energy for tillage is estimated according to the number of operations (from Table 1) and the energy consumption for each operation (Table 3). Average energy inputs for the six year period are presented. Energy outputs are calculated according to the average sugar beet yield. From the data presented it can be seen that the most intensive method of tillage was the conventional tillage. It demanded 2.998 MJ·ha^{-1} for soil preparation. With HC, energy inputs were reduced to 1.117 MJ·ha^{-1} (37%), with RC reduced to 1.183 MJ·ha^{-1} (39%), with DH reduced to 2.174 MJ·ha^{-1} (73%) and with NT to 2.953 MJ·ha^{-1} (98%) compared with the CT. However the NT required 1.605 MJ·ha^{-1} for the application of herbicide (*glyphosate or paraquat*). So, the net energy gain for the NT method was 2.953 – 1.605 = 1.348 MJ·ha^{-1}. Considering the total energy inputs for the crop production it can be noticed that the energy savings with the reduced tillage methods are 1,7-1,8% for the HC and RC, 2,1% for the NT and 3,4% for the DH. The small energy savings are due to the small participation of tillage to the total energy inputs (for the CT method it represents the 4,6% of the total energy inputs in the field). The margins for energy conservation are limited. The most important factor contributing 63,1% to the total energy inputs was irrigation followed by fertilization which accounted for 18,4% of total energy inputs in the conventional tillage. In the present study, underground water was used for irrigation and it was pumped from a depth of 80 m. Pumping underground water reserves for crop irrigation is the common practice in the region of Central Greece. However, the energy inputs through irrigation would have been much lower if over ground water reserves were to be used (from a cannal, or a river). In this case, about 11.085 MJ ha^{-1} would be required for irrigation (32% of the total energy inputs) and a much greater percent (8,6%) would be attributed to tillage, increasing by that way the margins for energy savings. Unfortunately, in the present experiment, the inputs were applied according to the higher yield requirements. It is possible though that no-till plots require less water.

Besides the energy savings, the reduced tillage methods where characterized by yield reduction. Statistical analysis proved significant differences between most of the treatments (Table 4). Conventional tillage was the highest yielding and gave an average production for the six years 74,7 t·ha^{-1}. Second best was the HC method which had 5,7% reduced yield. The methods of RC and DH had 18,3% and 22,7% reduced yields respectively, compared with the CT while the NT was the lowest yielding one and gave 53,8 t·ha^{-1} (28% reduction compared with the CT). A proportional reduction on energy outputs for the methods of reduced tillage was obtained (Table 4). The energy outputs were about 3-4 times greater than the energy inputs.

Considering the limited margins for energy conservation with tillage, it is obvious why a reduction on net energy, energy efficiency and energy productivity was achieved.

In the present study, agricultural supplies to all the methods of tillage were common and according to the needs of the highest yielding method (CT). However, if a yield reduction is to be expected with the adoption of a reduced tillage method, it is possible to achieve the same yield with a reduction on energy inputs through the rest of the energy additive factors (i.e. a reduced yield it is possible to have less demands on fertilizers, irrigation e.t.c). This approach could obviously lead to much greater energy savings and alter the energy coefficients in Table 4.

Table 4. Energy analysis for the five methods of tillage

	CT	HC	RC	DH	NT
Energy Inputs (MJ ha^{-1})					
Tillage	2.998	1.881	1.815	824	45
Fertilization	11.909	11.909	11.909	11.909	11.909
Seeding	665	665	665	665	665
Pesticides	3.889	3.889	3.889	3.889	5.494
Irrigation	40.922	40.922	40.922	40.922	40.922
Harvest	4.463	4.463	4.463	4.463	4.463
Total energy inputs (MJ ha^{-1})	64.846	63.729	63.663	62.672	63.498
Crop yield (t ha^{-1})	74,7	70,4	61,0	57,8	53,8
		CV = 14,98%, LSD$_{0,05}$ = 4,21			
Energy outputs (MJ ha^{-1})	220.711	210.839	180.772	173.581	160.527
Net energy (MJ ha^{-1})	155.865	147.110	117.109	110.909	97.029
Energy efficiency	3,40	3,31	2,84	2,77	2,53
Energy productivity (kg MJ^{-1})	1,15	1,10	0,96	0,92	0,85

CONCLUSIONS AND FUTURE WORK

Conventional tillage was the most intensive method in terms of energy use. It required 2.998 MJ ha^{-1} for soil preparation on a total energy budget of 64.846 MJ ha^{-1}. Because of the small percent that tillage consumes on the total energy inputs the margins for energy conservation were low. By adopting a reduced tillage method it was feasible to achieve 1,7-3,4% energy savings. However the methods of reduced tillage gave also reduced yields. The reduction was greater on the methods of RC, DH and NT (the methods with the shallower soil cultivation). As a result, a reduction on the terms of net energy, energy efficiency and energy productivity was obtained. The method of HC performed better than the other three reduced tillage methods and approached the CT. Taking also into account the significant environmental advantages that can be obtained with the adoption of a reduced tillage system, HC appears the best method for the substitution of the mouldboard plough. The perspectives would be much greater if the same yields could be achieved with reduced inputs mainly through fertilization and irrigation.

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