Fossil Fuel Deficit-Conservation Tillage and on Farm Biofuel Production to Cope With the Problem

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Abstract

The limited resources of fossil fuels along with the highly fluctuating prices, call for investigation to find diesel alternatives. Biofuels from vegetable oils, seems the easiest accessible substitutes as they can be used in conventional diesel engines without lot of modifications. There are though two mainstream attitudes on this approach. The one points that it is immoral to divert environmental resources from food production to energy production when the global population increases and the other claims that without mechanization and fuel to power it, food production will finally be decreased. Conservation tillage adoption may contribute in significant fuel savings by eliminating tillage operations. If they would be combined with on farm biofuel production, they would certainly require less land to be devoted for this purpose. In the present work, based on data of a long term tillage experiment, it was calculated the percentage of land that would be required to cultivate with a biofuel crop (sunflower for instance) in order to cover the fuel requirements of an arable farm, for three alternative tillage methods: conventional (CT), reduced (RT) and no-tillage (NT). The results indicated that in CT, the 11% of the land would be enough to provide the biofuel for all the field operations (except irrigation). In RT, due to lower fuel consumption, the 7.5% of the land would be sufficient. That means that a 3.6% yield reduction is justified. In NT, only the 3.5% of the land is required to produce the biofuels justifying a 7.7% yield reduction. This sets the limits of yield reduction that can be acceptable. However we have to add in this balance the environmental effects of using conservation tillage like erosion reduction, increasing soil organic matter and biodiversity maintenance.

Keywords: Biofuels, Food production, Conservation tillage, No-tillage, Sunflower

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Agricultural mechanization along with irrigation, biological improvements and chemical input development has been the main factors enhancing the agricultural production during the past decades. Agricultural mechanization was based on the use of fossil fuels to power the farm machinery. However, the limited resources of fossil fuels along with the highly fluctuating prices, call for investigation to find diesel alternatives. Especially E.U. is highly dependent on imported fossil fuels to cover its energy requirements (European Commission 2006). Existing knowledge and reports indicate that biomass derived liquid fuels such as vegetable oils and alcohols are the main alternatives we have at the moment (Biofuels Technology Platform 2008). They can be used in conventional diesel engines without lot of modifications (Ishii, Y and R. Takeuchi, 1987).

Vegetable oils are produced by oil seed producing crops after extraction. Extraction can be carried out by cold pressing or by chemical extraction (CIGR 1999). The later is more efficient industrial method while cold pressing is simple and can be used at farm level. In that way farmers have the chance to produce their fuels by their own. However there are two mainstream attitudes on this approach. The one points that it is immoral to divert environmental resources from food production to energy production when the global population increases (Rosillo-Calle and Hall, 1987) and the other claims that without mechanization and fuel to power it, food production will finally be decreased (Spiertz and Ewert, 2009).

Conservation tillage adoption may contribute in significant fuel savings by eliminating tillage operations (Sharma et al., 2011). If they would be combined with on farm biofuel production, they would certainly require less land to be devoted for this purpose. In addition there are a lot of environmental benefits of using conservation tillage like erosion reduction (Blanco-Moure et al., 2012), increasing soil organic matter (Sombrero and de Benito, 2010) and biodiversity maintenance (Perez-BrandÃąn et al. 2012) and conserving soil water (Cullum, 2012). Also in the last years a discussion about the benefits of using biofuels to the environment has started. Several papers have questioned the benefits from the energy crops to the environment, to the CO2 emissions and the effects to the food supply (Grahn at al., 2009).

Energy analysis of the cropping systems can offer the basis for assessing the benefits of an energy crop. In the present work, based on data of a long term tillage experiment, it was calculated the percentage of land that would be required to cultivate with a biofuel crop (sunflower for instance) in order to cover the fuel requirements of an arable farm, for three alternative tillage methods

I. Materials and methods

2.1. Experiment description

Data from a long term tillage experiment carried out in the Farm of University of Thessaly in central Greece were used for the analysis. The experiment started out in 1997 compared five alternative methods of soil tillage in a variety of arable crops. In years 2011 and 2012, fifteen years after the beginning the experimental field was cultivated with sunflower. Three of the compared tillage methods were chosen for the present analysis.

Conventional tillage (CT). This method represents the usual tasks carried out by local farmers for seedbed preparation. It involves deep ploughing at a depth of at least 25 cm during the autumn and repetitive passes, according to the conditions, with disk harrows and field cultivators for seedbed preparation at spring.

Reduced tillage (RC). It is a less common method in Greece though it's widely used in other parts of the world like USA and Australia. Primary tillage is accomplished with one pass at a medium depth of 20 cm of a heavy cultivator with spring type shanks while seedbed preparation is completed as in the conventional method though fewer passes are required.

No-tillage (NT). The lesser adopted method in Europe and completely unknown in Greece.

In the USA, about 30% of the cultivated land is considered to be under a form of no-tillage practice. In this method not any tillage operations are applied in the soil until planting. The crop is planted over the previous year crop and weed residue by using special robust seeders designed to work on hard conditions. In the present experiment, due to lack of such a seeder, a conventional pneumatic machine were used which however gave sufficient results. In no-till applications the weeds are usually destroyed with a total phase herbicide (e.g. glyphosate) before planting or immediate after, but for instance it wasn't necessary. The sunflower variety used in the present case (PR64LE29) allowed post-emergence application (for all the treatments) of a mixture of herbicides (fluazifop-P-butyl & tribenuron methyl) that controlled both narrow and broadleaf weeds. Along with the rapid development of the sunflower plants it was capable for the crop to compete sufficiently the weed populations.

Besides tillage, the rest of the cultivation practices were the same for all the treatments. The operations and inputs were recorded as shown in Table 1. Harvesting was done with an experimental plot harvester (HEGE 125) owned by the University Farm. Seed samples were used for cold pressing in a screw type press (Taby Press 1.5Hp) at the Lab. As no differences were obtained between tillage treatments, mean oil content for the seed was estimated.

TABLE 1. Schedule of tasks and inputs performed over the two years.

Year :	2011			2012		
Tillage treatment:	*CO*	*RC*	*NT*	*CO*	*RC*	*NT*
Soil Tillage (passes)						
Ploughing	1			1		
Heavy cultivator		1			1	
Disk harrow	2	2		2	2	
Field cultivator	1					
Sowing						
Row spacing (m)	0,75			0,75		
Population (seeds/ha)	90.700			78.000		
Seed used (kg/ha)	8,67			7,46		
Fertilisation						
N - P - K	93 - 51 - 51			95 - 63 - 63		
Herbicides						
fluazifop-P-butyl (kg/ha)	0,037			0,037		
tribenuron methyl (kg/ha)	0,312			0,312		
Irrigation						
Pumping depth (m)	80			80		
water supply (m^3/h)	50			50		
Traveller sprinkler (m^3/ha)	350			200		
Drip Irrigation (m^3/ha)	3260			3680		
Yield						
Seed weight (kg/ha)	4.120	3.954	3.255	2.875	2.506	2.132

2.2 Energy inputs estimation

Based on the records the direct and indirect energy (Pimentel 1992) consumption was estimated. Direct is the energy consumed in the farm, in the form of energy products, like fuel, lubricants and human labour. Indirect is the energy consumed outside the farm to produce any input (machinery, chemicals) used in the farm. Any material brought into the farm is considered as 'input' while any product sold to the market was added to 'output'. Products used in the farm were considered 'neutral'.

Indirect energy was estimated as the energy sequestered to the machinery during manufacturing. Machinery characteristics and data from Bowers (1992) were used for this purpose. The methodology is described in details by Cavalaris et al. (2008).

Direct energy was estimated from power and fuel consumption measurements in the field with the help of instrumentation added to the tractors (Papathanassiou et al. 2002) which allowed on-the-go measurement of draft and PTO power consumption. Fuel and energy consumption during the operations was estimated from the collected data. The energy content of diesel was considered 38.66 MJ/L. A fuel production and handling energy of 9.12 MJ/L were also taken into account (Leach 1976). The procedure is described by Cavalaris et al. (2008). The consumed energy by lubricants was also encountered as a 4% of the fuel energy (Fluck 1992). Finally, the energy spent for repair and maintenance was added. It was estimated as a percentage of the energy spent to produce the machine, using R&M coefficients (Bowers 1992)

Consumable goods were used in several stages of crop growth. For most of them there were energy sequestered values in the literature (Leach 1976, Pimentel 1992, Bowers 1992). A five tone capacity wagon toed by a 82 kW tractor with an average travel speed of 20 km/h was assumed for product transportation. The average distance from the field to the barn was assumed to be 5 km. Direct and indirect energy consumption was estimated (Cavalaris et. al. 2008).

Irrigation water was pumped from underground reservoirs and it was distributed by aluminum pipes and applied in the crop by traveler irrigators with gun sprinklers or by drip irrigation. The pumping plant was powered by electrical motor. Direct and indirect energy consumption for irrigation was estimated as described by (Cavalaris et. al. 2008).

For harvesting, both direct and indirect energy was estimated by literature data (Leach 1976). A screw type small size press with an electric motor of 1.1 kW (1.5 hP) and a capacity of 6-7 L of oil/h was used for oil extraction. An electric power meter connected in series to the press was used to measure power consumption during pressing. At the same time the processed seed and the produced oil were measured to estimate the energy per kg of seed processed or per liter of oil produced. The indirect energy for manufacturing, repairing and maintaining the press was added.

2.3 Energy output estimation

Sunflower outputs were only the harvested seed as the stalks were left in the field. Cold pressing of seed gave in average 33.5% oil and 66.5% cake. After sedimentation and filtering the oil was ready to use as an alternative fuel to diesel in the tractor engine. The energy content for oil was 36.8 MJ/kg and for cake 15 MJ/kg (Riva and Sissot 1999).

2.4 Energy budgets

For the energy budgets, mean values of inputs and outputs from the two years (2011 & 2012) were estimated. The net energy which is the energy output minus the energy input measured in MJ and the energy efficiency coefficient which is obtained by dividing the energy output by the energy input were calculated to evaluate the system. When an amount of vegetable oil was used to cover the fuel requirements of the enterprise, this amount was considered neutral and was excluded from the outputs. The discussed scenarios considered that the enterprise produces by its own the fuel required to power the autonomous vehicles moving in the field (tractor and harvester). Irrigation equipment used electric energy and so wasn't considered to be able to be powered from vegetable oils.

II. Results and discussion

At first, as can be seen on the 'energy budget' field in Table 2, the net energy for all the tested methods and scenarios are positive. This means that it is possible for the sunflower to be used as an energy crop. It should also be mentioned that the positive budget was obtained by considering as output only the seed as the stalks remained in the field.

By examining the energy inputs in Table 2 it is found that irrigation, fertilization and soil tillage are the most important factors representing 96% of total energy requirements in the field. Irrigation is the most important from the three covering almost 70% of total energy inputs in the conventional method. Unfortunately, sunflower can not give sufficient yields in Greece under dryland cultivation. It is interesting to mention that the high energy requirements are present because the water is pumped from underground reservoirs at a deep depth which is a common case for Greece. There are however areas which present a high underground water horizon or give the opportunity to use ground water resources from streams and canals. In that case, the energy consumption for irrigation could be even tenfold lower. Second in importance energy input is the use of fertilizers (Table 2).

In conventional tillage it represents 18,5% of total energy inputs. Even though nowadays industry efficiency of producing nitrogen fertilizers has increased (IFA, 2010), the use of nitrogen fertilization still appears as an intensive energy demanding practice. Reducing the amount of fertilizers will probably lead to reduction of yields.

TABLE 2. Energy budgets for sunflower im the three methods of tillage for two alternative scenarios for substitution of diesel fuel with vegetable oil.

	100% diesel - 0% oil			70% diesel - 30% oil			0% diesel - 100% oil		
Energy Budget	CT	RC	NT	CT	RC	NT	CT	RC	NT
Energy Inputs (MJ/ha)									
Tillage	4.326	2.193	0	3.161	1.605	0	441	232	0
Sowing	601	601	601	496	496	496	250	250	250
Fertilization	8.973	8.973	8.973	8.937	8.937	8.937	8.853	8.853	8.853
Pesticide application	81	81	81	64	64	64	23	23	23
Irrigation	33.528	33.528	33.528	33.528	33.528	33.528	33.528	33.528	33.528
Harvest	1.117	1.117	1.117	915	915	915	445	445	445
Transportation	61	56	47	52	48	40	31	28	24
Oil extraction				117	73	28	390	243	94
Total	48.686	46.548	44.346	47.269	45.665	44.007	43.961	43.603	43.216
Yield (kg/ha)									
Oil for trade	962	888	741	929	868	733	854	821	715
Oil for biofuel production				32	20	8	107	67	26
Cake	2.081	1.922	1.603	2.081	1.922	1.603	2.081	1.922	1.603
Total (seed yield)	3.043	2.810	2.344	3.043	2.810	2.344	3.043	2.810	2.344
Energy Outputs (MJ/ha)									
Oil	35.385	32.678	27.255	34.203	31.940	26.971	31.444	30.219	26.309
Cake	31.220	28.831	24.047	31.220	28.831	24.047	31.220	28.831	24.047
Total	66.606	61.509	51.301	65.423	60.772	51.018	62.664	59.050	50.355
Energy Budget									
Net Energy (MJ/ha)	17.920	14.961	6.955	18.155	15.107	7.010	18.703	15.448	7.139
Energy Efficiency	1,37	1,32	1,16	1,38	1,33	1,16	1,43	1,35	1,17
Fuel Scenarios									
Yield reduction	0,0%	7,7%	23,0%	0,0%	7,7%	23,0%	0,0%	7,7%	23,0%
Yield percentage required to cover the fuel demands				3,3%	2,3%	1,0%	11,1%	7,5%	3,5%
Total	0,0%	7,7%	23,0%	3,3%	9,9%	24,0%	11,1%	15,2%	26,4%

Soil tillage is the third most important factor of energy consumption in the field (Table 2). In conventional tillage it represents 9% of total inputs. Compared with CT, RC can reduce energy requirements at the half and NT uses no energy for seedbed preparation. Total energy consumption is reduced from 48,686 MJ/ha to 46,548 MJ/ha (4.5%) with RC and to 44,346 (9%) with NT.

Furthermore savings can be obtained if vegetable oil produced in the farm is used to power the farm machinery. For example, even with conventional method, total energy requirements are 43,961 MJ/ha (9.5% reduced) when machinery is powered with 100% vegetable oil. The savings rise up to 11% (total energy requirements 43,216 MJ/ha) if vegetable oil is used in combination with no-tillage.

However, the use of soil conservation tecniques resulted in sunflower yield reduction which in turn affected negatively the energy outputs. Moreover, using part of the seed to produce fuel oil means a further reduction of outputs. The yield reduction due to the application of conservation tillage was 7.7% for RC and 23% for NT. In the case of powering farm machinery with 70-30% diesel - biofuel mixtures, 3,3% of the seed has to be devoted for this purpose when using the conventional tillage method. In RC, 2.3% of the seed has to be used to produce fuel but there is also a 7.7% reduction in yield giving a total of 9.9% less product.

To remain competitive with CT method, yield reduction in RC mustnâĂŹt be greater than 3.3-2.2 = 1.1%. In NT, only 1% of the produced seed would be sufficient to give the fuel required to cover 30% of the energy for machinery operations. To be competitive with CT, yield reduction in NT shouldnâĂŹt be greater from 3.3-1=2.3%. The observed yield reduction however was 23%. When diesel fuel is substituted 100% by biofuel, 11.1% of the produced seed must be devoted to produce the fuel requirements for the CT method. This percent is reduced to 7.5% with RC, which means that there is an 11.1-7.5=3.6% margin for yield reduction that is however still smaller from the 7.7% observed in the experiment. In NT, 3.5% of the seed produced would be sufficient to power 100% of the farm machinery operations. The margin for yield reduction in NT compared to the CT method is 11.1-3.5=7.7%, significant smaller from the 23% obtained in the experiment.

From the presented analysis it can be concluded that if an amount of food resources (eg. sunflower seed) should be devoted to produce the necessary fuels to sustain agricultural production high, it is preferable to apply conventional tillage techniques that despite the higher energy demands, give higher yields. Of course conservation tillage techniques offer significant environmental benefits but in that case, the yield reduction shouldn't be greater from the limits discussed above. In the present experiment however, yield reduction was greater from the estimated limits. The lack of an appropriate no-tillage planter could be a possible cause for this. There are however many other experiments that report less or even no yield reduction when applying conservation tillage (Farooq et al., 2011, Sharma et al. 2011). More tillage experiments contacted in different regions with different soil and climate conditions would certainly offer a more complete aspect of the perspectives. The present work doesn't intend to give an answer at the immorality of using food resources for energy production. It however sets some important limitations to achieve this, in combination with conservation tillage techniques, with the less elimination in human food supplies.

III. Conclusions

Sunflower gave a positive energy balance and can be used as an energy crop for biofuels Reduced tillage offered energy savings of 4.5% while no-tillage offered savings of 9% compared with conventional. Average yield was 7.7% lower in RC and 23% lower in NT compared to CT. When using 70-30 diesel-biofuel mixture to power farm machinery, 3.3% of the produced seed or land cultivated must be devoted to this purpose in CT. In RC the percent is 2.3% and in NT 1%. The differences from CT give the marginal yield reduction in the conservation tillage methods. When powering farm machinery with 100% farm produced biofuel, 11.1% of the produced seed or land cultivated must be devoted to this purpose in CT. In RC the percent is 7.5% and 3.3% in NT. The differences from CT give again the marginal yield reduction. Conventional tillage due to higher yields sustains the higher food productivity even if an amount is used to produce the necessary fuels in the field. Yield reduction in conservation tillage methods shouldn't be greater than the limits mentioned above.

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