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Cost efficiency of different cropping systems encompassing the energy crop *Helianthus annuus* L.

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Abstract. Crop rotation and green manure are the most ancient and popular cropping systems. This study sought to analyze the economic efficiency of sunflower where pea (*Pisum sativum* L.) either harvested or incorporated at the flowering stage in the soil before the sowing of sunflower in Europe and the final agricultural profit of such a cultivation system. Therefore, the main objective of this paper is to report the production costs and to find out which of the tested cultivation system gets sunflower cultivation economically viable in Greece and in Mediterranean region. To assess the economic efficiency, three-year field experiments were established in two contrasting environments in central Greece (Trikala and Larisa) and contained three different cultivation practices using legumes comprised the main-factor (T_1: control, T_2: legume incorporated at the flowering stage, T_3: legume incorporated after seed harvest), while nitrogen fertilization comprised the sub-factor (N_1:0, N_2:50, N_3:100 and N_4:150 kgNha^{-1}). The results derived from this study revealed the positive effect of the legume incorporation treatment (T_2: legume incorporated at the flowering stage) where the final yield increased up to 5 t ha^{-1} regardless region. Moreover, depending on the year the T2 treatment increases the final yield 30–50% and a yield increase was also noticed to the treatment where the legume was harvested (T_3: legume incorporated after seed harvest). Therefore the introduction of this scheme into future land use systems in Greece and more generally in Mediterranean basin should be seriously taken into consideration.

Key words: sunflower, pea, monocrop, rotation, green manure.

INTRODUCTION

A challenge for sustainable agriculture is to identify those plants which are most efficient in forming stable soil structure and to incorporate them into economic rotational management systems. Several organic materials have been reported as suitable soil amendments for increasing crop production and the most ancient and famous are crop rotation and green manure (Ruis & Blanco-Canqui, 2017).

It is generally accepted that rotation with cover crops is fundamental for yield increase, as well as for controlling soil erosion and degradation, ground water pollution, and maintaining acceptable organic matter levels in the topsoil (Ruis & Blanco-Canqui, 2017). Soil organic matter represents a major proportion of the organic carbon within a terrestrial biosphere which plays an important role in soil fertility and affects infiltration, water retention, crop growth and productivity (Stępień et al., 2018). As a result, by conserving the soil its yield over time and generally agroecosystem sustainability are ensured (Powlson et al., 2001; Brennan & Smith, 2005; Tonitto et al., 2006; Ordonez et al., 2007; Imogie et al., 2008; Cattanio 2012; Isbell et al., 2017).

Legumes are included in crop systems due to the atmospheric N fixation of nitrogen and are the finest external options that can be used to enhance the efficiency of nitrogen use (Thorup-Kristensen et al., 2003; Fageria & Baligar, 2005; Dorn et al., 2015). *Pisum sativum* has great potential among legume species that could be used as cover crops, as it is well adapted to Mediterranean-type crops with thriving cultivation techniques (Miller et al., 2003). Residue quality is usually associated with two factors: the time to preserve its physical characteristics, and the supply of carbon and mineral elements from its decomposition. These two aspects are affected by both the climate and the structure of the residue (Vergani & Graf, 2015; Bacq-Labreuil et al., 2018) It has been reported (Voroney et al., 1989) that the fixation of organic carbon from pea residuewould sequester 212–318 kg of C ha^{-1}.

Nitrogen (N) is one of the most important elements in the metabolic processes of plants such as protein synthesis and photosynthetic processes. Consequently its use is necessary in order to maximize yields and quality of crops worldwide (Ahmad et al., 2009; Massignam et al., 2009; Ullah et al., 2010).

Nitrogen is a limiting factor that prevents yield in many crops such as sunflower. Sunflower growth depends more on nitrogen than any other nutrient (FAO, 2010). Thus, meeting the needs of the plant in N is necessary for the crop to be profitable (Mortvedt et al., 2003). More specifically the requirements of the sunflower in nitrogen reach 100 kg N ha^{-1} in order to have a good yield (Malligawad et al., 2004). However, nitrogen fertilization is quite variable and depends largely on the soil type and the climate conditions of the area (Chapman et al., 1993; Lauretti et al., 2007). Sunflower has a mean rooting depth of 50 cm that varies with different cultivation managements (e.g. tillage system) (Gajri et al., 1997). Water consumption of sunflower may range from 200 to over 900 mm per season, depending on many factors (like latitude, soil-climate conditions, sowing period and management (Gajri et al., 1997; Debaeke et al., 1998; Karam et al., 2007).

Moreover, it is well documented that sunflower is a crop with low water use efficiency (Rinaldi, 2001; Goskoy et al., 2004), while Mediterranean areas are characterized by mild temperatures and high water availability early in the season, but later on and especially during summer due to greater temperatures and minimum rainfalls, irrigation application seems inevitable (Soriano et al., 2004). In order to reach high seed yields, sunflower should be irrigated at least three times during its growing period, especially during heading, flowering and milking stage, with full or limited irrigation water (Goskoy et al., 2004). Responses to fertilization are also influenced by weather conditions and soil water availability (Lopez-Bellido, 2003). Studies have shown that the optimum amount of N-fertilization is found mainly in the range of 40–190 kg N ha^{-1}, depending on soil type and previous crop (Sirbu et al., 1992; Glas, 1998).

Nitrogen is very essential for plant growth and makes up 1–4% of dry matter of the plants. Moreover, in the case of the comparison between a mono-crop system (industrial crop-industrial crop) and a crop-rotation system (industrial crop - leguminous crop rotation), N application averages 18% and 13% of the variable costs, respectively (Duvick & Cassman, 1999).

There are no data reported about the cost performance of *Pisum sativum*, either harvested or incorporated in the soil before the sowing of sunflower in Europeand the final agricultural profit of such a cultivation system. Therefore, the main objective of this paper is to report the production costs and to find out which of the tested cultivation system makes economically feasible sunflower cultivation in Greece and the Mediterranean region generally.

MATERIALS AND METHODS

Field experiment

Two field experiments were established in two different soils, e.g. in Trikala (West Thessaly; coordinates: 39032 mottle 17.08′ ppl N, 21046 mottle 17.19′ E, 120 m asl)) and in Larisa (East Thessaly; coordinates: 39030 mottle 02.85′ ppl N, 22042 mottle 50.37′ E, 60 m asl), central Greece.

The soil in Larisa (plough layer) is a calcareous (pH: 8.0) clay (sand 2%, silt 35%, clay 63%), fertile (organic matter content 1.7% at 20 cm depth) and was classified as Vertisol (Soil Survey Staff, 1993), while the soil in Trikala area(plough layer) is deep, calcareous (pH: 7.4), sandy clay loam (sand62%, silt 17%, clay 21%), fertile (1.25% organic matter content at 30 cm depth). The soil is characterized as Entisol (Aquic Xerofluvent; Soil Survey Staff, 1993).

Table 1. Agronomic data of pea and sunflower cultivation for both experimental years and location sites

	TRIKALA	
	1st year	2nd year
PEA		
Date of sowing	5/12/2012	1/12/2013
Date of 50% emergence	20/12/2012	27/12/2013
Date of incorporation	13/04/2012	11/4/2013
Average density of plants per m^2	150	150
SUNFLOWER		
Date of sowing	10/06/2012	15/06/2013
Date of 50% emergence	17,19/06/2012	21/06/2013
Date of harvest	1,3/10/2012	1/10/2013
Average density of plants per m^2	20	20
Maximum irrigation applied (mm)	320	350
	LARISA	
PEA		
Date of sowing	5/12/2012	15/11/2013
Date of 50% emergence	20/12/2012	1/12/2013
Date of incorporation	12/04/2012	15/04/2013
Average density of plants	150	150
SUNFLOWER		
Date of sowing	10/06/2012	13/6/2013
Date of 50% emergence	14,19/6/2012	19,20/6/2013
Date of harvest	2/10/2012	1/10/2013
Average density of plants	20	20
Maximum irrigation applied (mm)	320	350

For the purposes of the study sunflower (Hybrid *Panter*) was sown using a modern pneumatic seeding machine and the population was 7 plants m^{-2} for both sites. The experimental used design was a factorial split plot with three replications (3 blocks) and 12 plots per block. Three different cultivation practices using legumes (*Pisum sativum* L., cv. caroubi) comprised the main-factor (T_1: control; T_2: legume incorporated at the flowering stage, average 6,000 kg ha^{-1} dry yield; T_3: legume incorporated after seed harvest), while nitrogen fertilization comprised the sub-factor (N_1: 0, N_2: 50, N_3: 100 and N_4: 150 kg N ha^{-1}). The second dose (nitrate form) was applied on the onset vegetative phase of sunflower, at plant height approximately up to 60cm. Sowing dates and other relevant agronomic data are summarized in Table 1. Fertilization for pea was 60 kg Pha^{-1}

(superphosphate) as basal dressing. The amount of dry biomass of pea incorporated in the top soil was measured directly by means of destructive sampling upon full flowering each year.

During the harvest period (seed maturation) in both areas, a destructive sampling took place by hand, where 1 m^2 in every plot was harvested.

It should be noticed that proper nutrient uptake determinations require at least one extra year of field experimentation, with the plots with same fertilization levels placed exactly at the same position to minimize any residual effect from previous fertilization. This was the case in both field experiments here. The presented data correspond to 2012 and 2013 experimental years, where the crops were sown in the same position for the 2nd and 3rd growing period.

Economic Parameters - Trade off analysis

Besides the agronomic aspects of a cultivation system, analysis of cost–benefit ratio mainly demonstrates farmer's profitability. To assess this, on farm budgets were constructed including three scenarios: i. sunflower as a single crop (mono-crop system), ii. Sunflower as a second crop after legume incorporated at the flowering stage (rotational system), iii. Sunflower as a second crop after legume incorporated after pea seed harvest (rotational system).

The economic costs of the cultivation systems were land rent and establishment costs of each cultivation such as plowing, cheelering, harrowing, sowing, herbicide application, seeds, irrigation, fertilization, incorporation and labor costs for the preparation of the above practices (€ $hour^{-1}$ multiplied with the sum of the needed hours per hectare; existing market prices in Greece were considered), and harvesting costs which depend on the crop (Table 2). Furthermore, to calculate economic returns (per hectare); for the each crop, existing market prices in Greece were considered (the prices refer to the average prices obtained from the survey carried out in the local area during the experimental period). To construct such databases, material and operation costs were considered as well as the local market prices (0.38 and 0.50 € kg^{-1} for sunflower seed and pea grain, respectively).

Table 2. *Pisum sativum* and *Helianthus annuus* cultivation costs in central Greece

€ ha^{-1}	*Pisum sativum incorporated at seed harvest*	*Pisum sativumincorporated at the flowering stage*	*Helianthus annuus*
Culivation costs			
Weed management (labor)	15	15	15
Plowing	90	90	90
Cheeler	40	40	40
Harrowing	60	60	60
Sowing	20	20	30
Seeds	170	170	50
Irrigation	0	0	300
Fertilization	15	15	15
Fertilizer (46-0-0)	150	150	0
Land Rent	700	700	0
Harvest Cost	200	0	150

Statistical analysis

The statistical package GenStat (7th Edition) was used for the analysis of variance (ANOVA) within sample timings for all measured and derived data. The $LSD_{0.05}$ was used as the test criterion for assessing differences between means (Steel & Torrie, 1982).

RESULTS AND DISCUSSION

Sunflower Yield

The positive effect of nitrogen fertilization to the final seed yield of sunflower has been mentioned worldwide (Rinaldi et al., 2001; Zubillaga et al., 2002; Ruffo et al., 2003; Göksoy et al., 2004; Albrizio & Steduto, 2005). The same was also noticed in this study, where the two higher nitrogen fertilization applications (N_3, N_4; 4–4.2 t ha^{-1}) produced 1-1.2 t ha^{-1} higher yield in comparison with the lower levels (N_1, N_2; 3 t ha^{-1}) for both years and areas (Table 3).

The most impressing finding was the positive effect of the legume incorporation treatment (T_2) where the final yield increased up to 5 t ha^{-1} in 2012 for both areas, while in 2013 remained in lower levels 4.72 t ha^{-1}. The higher harvested yield in 2012 was noticed due to higher precipitation during the seed filling stage. Therefore, depending on the year the T_2 treatment will increase the final yield 30–50% which is in agreement with literature (Thorup-Kristensen & Dresboll, 2010). This is due to the nitrogen-binding capacity of the pea, and in particular, during the flowering stage where the nitrogen (N), phosphorus (P) and potassium (K) contents are 10, 3.15, and 3%, respectively, for both sites (data not shown). Finally, it has to be mentioned that there was also found a yield increase to the treatment where the legume was harvested (T_3), which also agree with Stępień et al. (2017) where it is reported an influence of crop rotation on rapeseed seed yield.

Table 3. Sunflower seed yield (kg ha^{-1}) as affected by three cultivation practices and four nitrogen fertilization levels

	Seed Yield Larisa 1st year (kg ha^{-1})	Seed Yield Larisa 2nd year (kg ha^{-1})	Seed Yield Trikala 1st year (kg ha^{-1})	Seed Yield Trikala 2nd year (kg ha^{-1})
T_1	2,537	3,295	3,019	3,895
T_2	4,165	5,197	5,288	5,123
T_3	3,415	4,116	3,844	3,956
$LSD_{0.05}$	*686.0*	*789.7*	*91.4*	*692.7*
N_1	2,826	3,753	3,222	3,283
N_2	3,194	3,887	3,970	3,643
N_3	3,597	4,376	4,432	3,633
N_4	3,663	4,154	4,576	3,784
$LSD_{0,05}$	*209.0*	*103. 8*	*302.5*	*536.4*
CV(%)	*5.5*	*14.5*	*12.3*	*12.0*

*(T_1: control; T_2: legume incorporated at the flowering stage; T_3: legume incorporated after seed harvest; N_1: 0; N_2: 50; N_3: 100 and N_4: 150 kg N ha^{-1}).

It is really important to be mentioned that in sandy soils such as in Trikala, significant yields on seed can be achieved with only small nitrogen applications if the cultivation practice of crop rotation, and in particular that of green fertilization using legumes and in particular peas.

In higher fertility, clay soils such as Larisa, crop rotation has clear benefits in organic carbon and enzyme activities and is related to the percentage of the organic matter as well as the total percentage N. The deep, perennial root system of sunflower utilizes the maximum of the nutrients (Omay et al., 1997; Potter et. al., 1998; Ashraf et al., 2004; Sainju et al., 2006; Lopez-Belido et al*.,* 2010; Melero et al., 2011).

Pea Yield

The blossom stage of pea begins at the Growing Degree Days of 350 °C-d while the seed maturation takes place at 820 °C-d in Larisa and at 947 °C-d in Trikala. The seed growing rate is 100–120 kg ha^{-1} per day, while the final yield reaches the 2,180 kg ha^{-1} in Larisa and the 1,930 kg ha^{-1} in Trikala. The small no significant difference (data not shown) to the final seed yield of the sites is due to the lower soil fertility of the sandy soil in Trikala. Finally, it must be mentioned that pea cultivation reaches the maximum dry yield at the Growing Degree days of 450 °C-d, which is the best period for the incorporation.

Production Costs

The total costs for the different cultivation practices of sunflower using legumes (T_1: control, T_2: legume incorporated at the flowering stage, T_3: legume incorporated after seed harvest) and the different nitrogen fertilization levels (N_1:0, N_2: 50, N_3: 100 and N_4:150 kg N ha^{-1}) are summarized in Fig. 1.

As it was expected, higher average production costs were reported in the case of the T_3N_4 treatment (legume incorporated after seed harvest with 150 kg ha^{-1} nitrogen fertilization), where costs are increased by the fertilization costs and the harvest costs of pea and totally agree with previous findings (Liebman et al., 2012). The required expenses for this case are 1,920 € ha^{-1}. On the other hand, the case with the lower average production costs was the T_1N_1 treatment (control) where the required expenses are 820 € ha^{-1}.

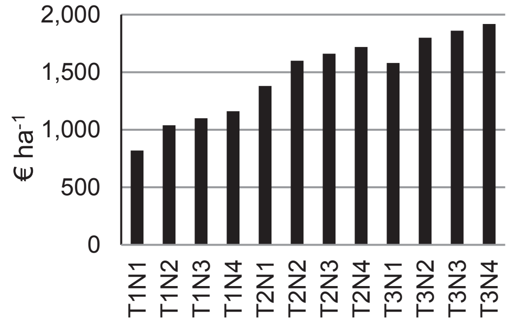

Figure 1. Sunflower cultivation costs as observed in Thessaly plain and as affected by three cultivation practices and four nitrogen fertilization levels. (T_1: control; T_2: legume incorporated at the flowering stage; T_3: legume incorporated after seed harvest; N_1: 0; N_2: 50; N_3: 100 and N_4: 150 kg N ha^{-1}).

Cultivation Profit

Higher profit was found for the treatment where sunflower was harvested as a second crop where pea seed was harvested and the biomass of the legume was incorporated regardless area and year. The average profit for this treatment was 883 € ha^{-1} having a significant difference with the cultivation practice of sunflower as mono-crop system (Table 4).

In the case of the nitrogen fertilization (Fig. 2; Table 4), there was found significant difference for the higher fertilization levels (N_3, N_4) comparing with the lower (N_1, N_2). Moreover, it was found that the cost of the used nitrogen had a negative effect for the treatment with the 150 kg N ha^{-1} (Table 4).

Table 4. Sunflower profit (€ ha^{-1}) as affected by three cultivation practices and four nitrogen fertilization levels

	Profit (€ per ha)				
T_1	143	T_1N_1	225	T_3N_2	858
T_2	456	T_1N_2	53	T_3N_3	945
T_3	883	T_1N_3	137	T_3N_4	907
LSD0.05	467.8	T_1N_4	156	*LSD0.05*	379.3
N_1	441	T_2N_1	273		
N_2	429	T_2N_2	376		
N_3	563	T_2N_3	609		
N_4	543	T_2N_4	567		
LSD0.05	77.8	T_3N_1	824		
CV (%)	12.1				

*(T_1: control; T_2: legume incorporated at the flowering stage; T_3: legume incorporated after seed harvest; N_1: 0; N_2: 50; N_3: 100 and N_4: 150 kg N ha^{-1}).

As illustrated in Fig. 2, farmers' profit 53 to 225 € ha^{-1} for the single culture of sunflower (cropping scenario monoculture T_1), from 273 to 609 € ha^{-1} and from 824 to 945 € ha^{-1} for the multiple cropping system of sunflower after legume (cropping scenarios T_2, T_3).

Therefore, the above results show a high dependence of sunflower cultivation as a second crop while the extra fertilization of 150 kg N ha^{-1} decreases farmers' profit, with the scenario of incorporation the biomass of pea cultivation after seed harvest and sunflower as second cultivation being more feasible.

Based on the above scenarios, sunflower cultivation as monoculture seems to be not feasible due to the low profit (143 € ha^{-1})if someone includes the fact of the fragmentation of rural land and therefore a farmer needs more than 100 hectares to ensure a sustainable annual income by taking into account the costs of the next year.

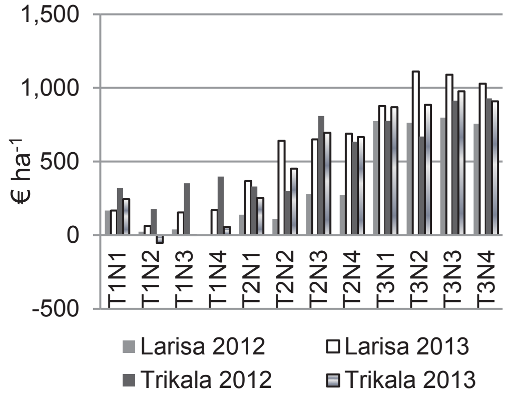

Figure 2. Farmer's profit from sunflower cultivation as observed in Thessaly plain during 2012 and 2013 and as affected by three cultivation practices and four nitrogen fertilization levels. (T_1: control; T_2: legume incorporated at the flowering stage; T_3: legume incorporated after seed harvest; N_1: 0; N_2: 50; N_3: 100 and N_4: 150 kg N ha^{-1}).

Trade off analysis

The economic analysis is for the 2nd and 3rd growing years (2012 and 2013). Finally, sensitivity analysis was used to estimate the effect of product price to crop income benefits for the most viable cultivation system (T_3N_3; 945 € ha^{-1}) estimating that the yield is stable.

Table 5. 2-input table for the T_3N_3 treatment and different seed yield price

Seed Price € per ha	Pea										
Sunflower	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45	0.50	0.55	0.60
0.10	-	-	-	-	-	-	-	-	-	-	-
0.15	-	-	-	-	-	-	-	-	-	-	-
0.20	-	-	-	-	-	-	-	-	-	+	+
0.25	-	-	-	-	-	-	-	+	+	+	+
0.30	-	-	-	-	-	+	+	+	+	+	+
0.35	-	-	-	-	+	+	+	+	+	+	+
0.40	-	-	+	+	+	+	+	+	+	+	+
0.45	+	+	+	+	+	+	+	+	+	+	+
0.50	+	+	+	+	+	+	+	+	+	+	+
0.55	+	+	+	+	+	+	+	+	+	+	+
0.60	+	+	+	+	+	+	+	+	+	+	+

*(T_3: legume incorporated after seed harvest; N_3: 100 kg N ha^{-1}).

Therefore, as it shown in Table 5, in case that sunflower seed price is stable at 0.50 € kg^{-1}, the lower price that pea seeds can get is 0.10 € kg^{-1}, while if the seed price of pea is stable the lower price that sunflower seed can get is 0.30 € kg^{-1}. In Table 5 are presented all the price combination for the scenario of pea harvest and the remaining biomass incorporated and the cultivation of sunflower as second crop with nitrogen fertilization of 100 kg ha^{-1} (T_3N_3).

CONCLUSION

Through the different tested cropping systems, single sunflower cropping and multiple cropping of legume followed by sunflower, it was found that the single crop scheme is not economically viable. There was a higher profit for the treatment where sunflower was harvested as a second crop after pea harvest and the remaining biomass is incorporated, irrespective of area and year. The most impressive finding was the positive effect of treatment with legume incorporation with an increase in yield up to 5 t ha^{-1} regardless of region. Depending on the year the incorporation of legume may increases the yield by 30–50 percent while for the treatment where the previous cultivation was legume was also noticed a yield increase.

As a general conclusion, the sunflower cultivation system after pea cultivation appears to be a successful cropping scenario, characterized by high profit for farmers with a possible further rise in profit by enhancing the final yield or raising the seed selling price, and therefore, serious consideration should be given to the implementation of this system into future land use schemes in Greece and, more usually, in the Mediterranean basin.

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