 doi:10.20944/preprints202211.0339.v1

Article

Effect of different tillage practices in Sunflower (*Helianthus annuus*) cultivation in a crop rotation system with intercropping Triticosecale -Pisum sativum

Aikaterini Molla[1]*, Georgios Charvalas[2], Maria Dereka[3], Elpiniki Skoufogianni[4]

[1] *Laboratory of Soil Science, Department of Agriculture, Crop Production and Rural Environment, University of Thessaly, Fytokou Street, 38446, Volos, Greece; katrinmol@yahoo.gr*
2 *Laboratory of Development and Protection of Rural and Mountains Areas, Department of Planning and Regional Development, University of Thessaly, Pedion Areos., 38334, Volos, Greece; gcharval@gmail.com*
[3] *Department of Agrotechology, University of Thessaly, Gaiopolis, 41500, Larissa, Greece; maroula.dereka@gmail.com*
[4] *Laboratory of Agronomy and Applied Crop Physiology, Department of Agriculture, Crop Production and Rural Environment, University of Thessaly, Fytokou Street, 38446, Volos, Greece; eskoufog@uth.gr*
* Correspondence author: katrinmol@yahoo.gr (A.M.); Tel: 00306936963820

Abstract: The objective of this work was to investigate the effect of different soil tillage practices in sunflower cultivation in a rotation system with intercropping *Triticosecale x Pisum sativum*. For this purpose a two year experimental field of 5% slope was established in central Greece. There were four treatments with three replications each. The treatments were: (a) no tillage - planting parallel to the contour (NTC-PAC), (b) conventional tillage - planting parallel to the contour (CTC-PAC), (c) no tillage - planting perpendicular to the contour (NTC-PEC), (d) conventional tillage - planting perpendicular to the contour (CTC-PEC). During the experiment plant height, leaf area index, specific leaf area, plants' total nitrogen and plants' proteins were measured. According to the results plant height ranged from 64.9 (CTC-PAC) to 85.2 cm (NTC-PEC) the 1st year and between 66.5 – 86.5 cm in CTC-PAC and NTC-PEC treatments in the 2nd year. Furthermore, LAI and SLA, plant's total nitrogen and protein content and N-uptake were affected positively by the no tillage practice. To conclude, sunflower is a promising crop in a rotation system with intercropping *Triticosecale x Pisum sativum*, cultivating under rainfed sloping conditions.

Keywords: LAI; SLA; N-uptake; total nitrogen; Greece

---

1. Introduction

Sunflower (Helianthus annuus L.) belongs to the Compositae family and is a native crop in North Amerika. It was introduced into Europe in 1510 by Spanish explorers [1]. Additionally, sunflower is one of the most important new edible oil crop worldwide and it is also a desirable crop which can be satisfactorily cultivated in intensive dryland rotations [2]. Its oil has a high content of not synthesized by humans' fatty acids (linoleic and oleic acids) and it is used widely in the food industry instead of olive oil [3, 4]. Furthermore, sunflower oil is used for the biodiesel production, reducing the negative impacts of non-renewable energy sources that have harmful effects in environment and in society [5].

In many countries all over the world the raise of the fertilizers' price in combination with the increasing of fossil fuels' cost had led the producers to turn their interest in conservation agriculture which including lower impact cultivation practices such as no tillage cultivation, permanent crop residues on the surface and crop rotation [6, 7]. The conservation tillage is able to significantly improve soil properties (physical, biological, and chemical) and other biotic factors, reduce the soil erosion, improve the water infiltration and also helps in the reduction of the production's costs [8-10].

Preprints (www.preprints.org) | NOT PEER-REVIEWED | Posted: 17 November 2022 doi:10.20944/preprints202211.0339.v1

Nitrogen (N) is the most essential nutrient in agricultural production. It plays an important role in crops' photosynthesis and in total biomass increase of the Hellianthus annuus. Zubillaga et al. [11] have showed that the sunflower biomass increased from 19 to 40% when an optimum nitrogen amount was applied. In addition, nitrogen fertilizer had positive effects on sunflower dry yield according to other researches [12, 13]. On the other hand, nitrogen is considered to be one of the costliest inputs in agricultural management [14].

It is well known that legumes have the ability to fix the atmospheric N. Haugaard - Nielsen et al. [15] indicated that nitrogen uptake by legumes was higher in a rotation system compared with a monoculture system. Miller et al. [16] have mentioned that pea fixes more atmospheric N than lentil and cowpea. Pisum sativum residues in a rotation system have beneficial effects on agronomic plant characteristics and on total crop production wherefore the nitrogen requirements of the succeeding crops reduce and additionally less nitrogen fertilizer applied [17]. According to Skoufogianni et al. [18] the pea incorporation in a rotation system (pea – maize and pea – sunflower) increased the biomass and the nitrogen use efficiency.

The use of alternative cultural practices such as using no tillage (direct seeding) can be enhanced by the farmers. The no tillage practice is one of the three fundamental principles of the conservation agriculture. This practice provokes a better protection against soil erosion and offers a greater efficiency in the nutrients uptake by plants [19, 20].

The contour tillage is a more sustainable practice in comparison to that usually expected in flat fields (in straight lines) or that along-the-slope tillage. Adverse effects become more pronounced under intensive rainfall events. Contour cultivation on fields with high inclination percentage can decrease soil erodibility, increasing thus topsoil resistance [21].

Information on the effect of cover crop using legumes, no tillage cultivation in combination with different planting systems (parallel and perpendicular to the contour) in the sunflower cultivating in a sloping land is lucking.

For this reason we examined the effect of a two years rotation system including *Triticosecale – Pisum* sativum as winter cultivation and *Helianthus annuus* as summer cultivation with different tillage practices (conventional and no tillage), planting parallel and perpendicular to the contour on a dryland sloping field on sunflower growth and quality under Geek climate.

The aims of this work were to measure plant height, leaf area index, specific leaf area, plant's total nitrogen and protein content and N uptake of the sunflower cultivated under the above agricultural conditions.

2. Results

2.1. Meteorological data

The meteorological data are presented in Figure .1. Total precipitation levels were 412.5 mm, and 439 mm in 2015–2016, 2016–2017, respectively. During the growing periods of Sunflower (June – October) the precipitation was 226.6 mm the 1st year and 187mm the 2nd year. The higher rainfall events were in September and in October. The temperature was at least 3^{o}C higher the 2nd year compared to 1st year.

 doi:10.20944/preprints202211.0339.v1

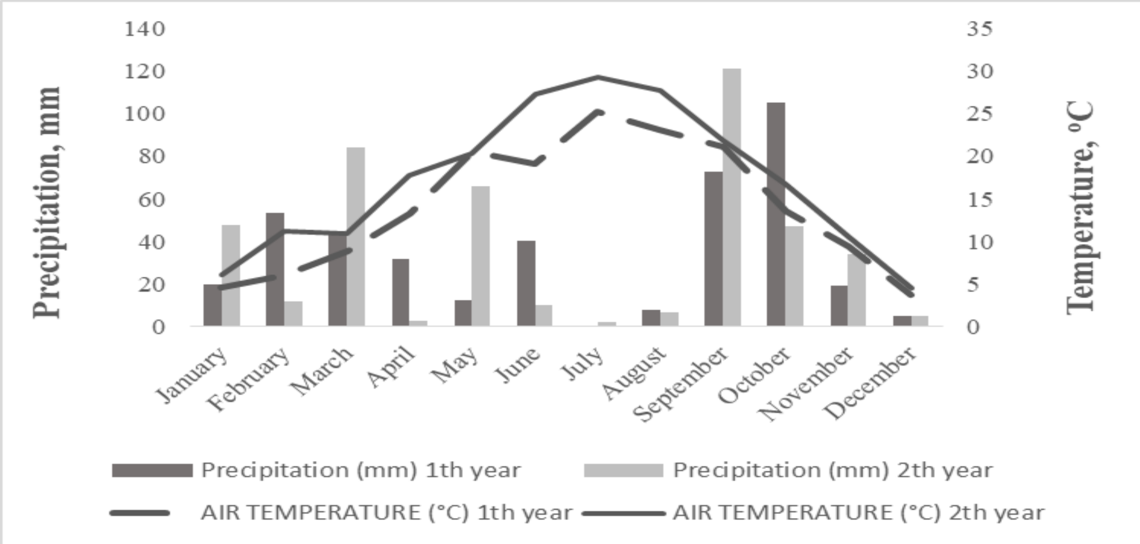

Figure 1. Average temperature (°C) and precipitation (mm) in the studied area during 2015-2016 and 2016-2017 cultivation years.

2.2. Plant height

The plant height results are illustrated in Fig. 3. The height ranged from 64.9 to 85.2 cm the 1st year and from 66.5 to 86.5 cm the 2nd year. In all the treatments the height was higher in 1st growing period compared to 2nd year. Furthermore, the highest plant height were observed in no tillage cultivation, planting parallel to the contour treatment both in two studied growing seasons following by the conventional parallel to the contour tillage. Compared to the direction of planting tillage (parallel and perpendicular to the contour), even though there were no statistically significant differences among the treatments, the parallel to the contour tillage increased the height of the plants. Additionally, the no tillage treatment resulted in the highest plant height each year, regardless of tillage direction.

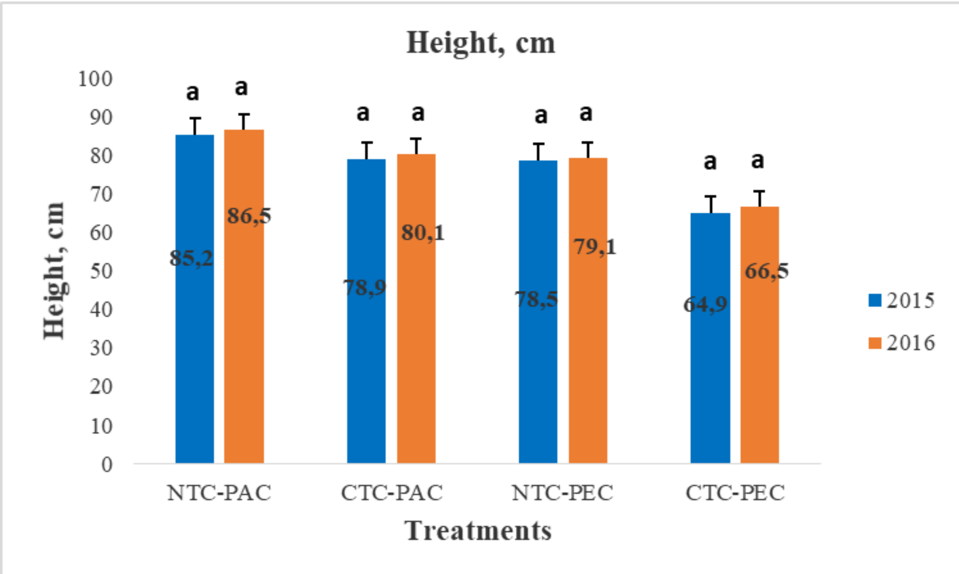

Figure 3. Plant height (cm) of the sunflower cultivation in two growing years.

2.3. Leaf area index (LAI) - Specific leaf area (SLA)

The results of leaf area index and Specific leaf area are reported in Figures 4 and 5. Three measurements of LAI and SLA were conducted, the 1st year in 28/7/2015, 27/8/2015, 15/9/2015 and the 2ndyear in 18/7/2016, 16/8/2016, 4/9/2016. The different tillage practices affected LAI only in the 2nd measurement, both in two growing years. Statistically significant difference was observed between the NTC-PAD and CTC-PEC treatments. In the 1st and 3rd measurements there were not statistically significant differences between the treatments. In two cultivation years of experiments the maximum leaf area index (LAI) recorded at no tillage - planting parallel to the contour direction (NTC-PAD) treatment. The 1st year the maximum values of LAI ranged from 3.6 (CTC-PEC) to 3.9 (NTC-PAC) and from 3.5 (CTC-PEC) to 4.01 (NTC-PAC) the 2nd year. According to our results the higher LAI values (3.9 the 1st year and 4.01 the 2nd year) were observed when 134 (40 kg ha^{-1} from the fertilization plus 94 kg ha^{-1} from the incorporation of the Triticosecale - Pisum sativum cultivation) and 142 kg ha^{-1} (40 kg ha^{-1} from the fertilization plus 102 kg ha^{-1} from the incorporation of the Triticosecale - Pisum sativum cultivation) of nitrogen were applied the 1st and 2nd year, respectively. Tillage systems had affected the specific leaf area but only numerically. No statistically significant difference was observed between the different treatments. Mean values showed that the highest SLA was achieved in no tillage - planting parallel to the contour direction (NTC-PAC) treatment.

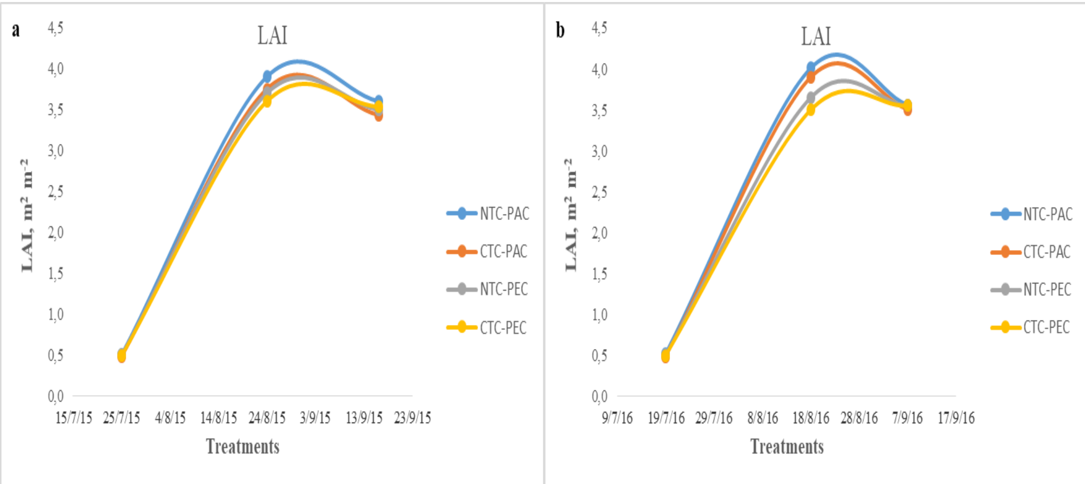

Figure 4. Leaf area index (LAI) of the sunflower cultivation in two growing years (a) 2015-2016 and (b) 2016-2017.

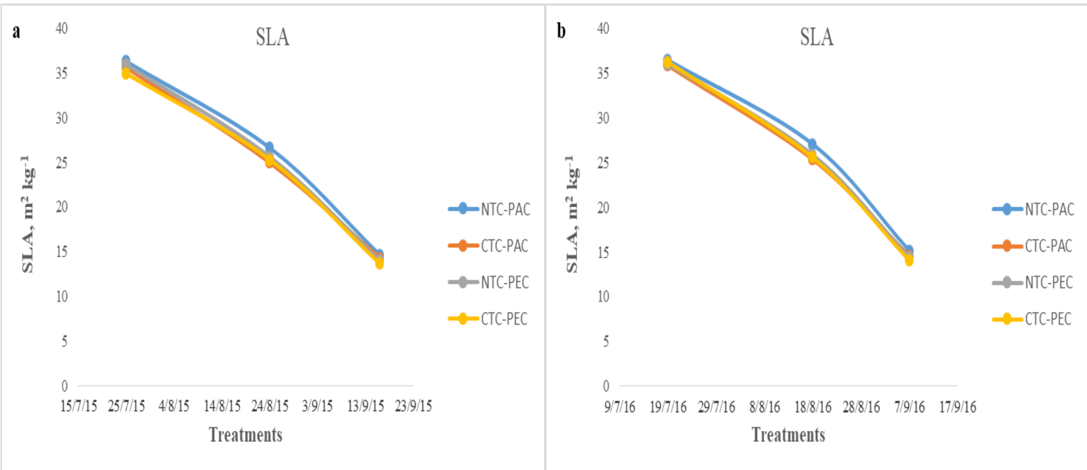

Figure 5. Specific leaf area (SLA) of the sunflower cultivation in two growing years (a) 2015-2016 and (b) 2016-2017.

2.4. Total nitrogen content in plants

Data regarding plants' total nitrogen presented in Tables 1 and 2. The first year the highest total nitrogen (%) was observed in NTC-PAC treatment (4.388%) and the lowest in CTC-PEC (4.153%). The 2nd year the mean values of total nitrogen ranged from 4.175 (CTC-PAC) to 4.435% NTC-PEC). In both cultivation years statistically significant difference was observed between the NTC-PAC and the other treatments. The parallel to the contour planting gave better results compared with the perpendicular to contour tillage, both in two years of experiments. The 1st year (2015) the total nitrogen in NTC-PAC treatment was higher by 3 – 5% in comparison with the other treatments. The 2nd year (2016) the increase of total nitrogen in the NTC-PEC ranged from 3 to 6%. Between the two cultivation years the total nitrogen was better in the 2nd year. The highest increase was noticed in the CTC-PAC treatment (2%). That total nitrogen increase probably derived from the nitrogen residual of the previous cultivation year and from the *Triticosecale – Pisum sativum* residues which incorporated the 2nd growing year. Furthermore, the 2nd year the rainfall in time of incorporation accelerated the residues of the winter crops to be decomposed.

Table 1. Total Nitrogen (%) of the *Helianthus annuus* cultivation in the 4 different soil practice treatments in the 1st growing year.

	Total Nitrogen, %		CV %
Treatment	***Helianthus annuus***		
NTC-PAC	4.388	**c**	8.15
CTC-PAC	4.251	**b**	3.22
NTC-PEC	4.250	**b**	1.76
CTC-PEC	4.153	**a**	6.15
LSD		**0.0263**	

Table 2. Total Nitrogen (%) of the *Helianthus annuus* cultivation in the 4 different soil practice treatments in the 2st growing year.

	Total Nitrogen, %		CV %
Treatment	***Helianthus annuus***		
NTC-PAC	4.435	**a**	6.75
CTC-PAC	4.320	**a**	2.25
NTC-PEC	4.310	**a**	8.55
CTC-PEC	4.175	**a**	4.31
LSD		**0.0245**	

Different letters at each column denote statistically significant difference of means according to the LSD test for 95% significance level ($p < 0.05$).

NTC-PAC: no tillage – planting parallel to the contour direction
CTC-PAC: conventional tillage – planting parallel to the contour direction
NTC-PEC: no tillage – planting perpendicular to the contour direction
CTC-PEC: conventional tillage - planting perpendicular the contour direction

2.5. Protein content

The results of the plants' protein content are illustrated in tables 3 and 4. The highest protein content was observed in NTC-PAC treatment (27.43) and the lowest in CTC-PEC (25.97). The 2nd year the mean values of proteins ranged from 27.72 (CTC-PAC) to 26.09 (NTC-PEC). In both cultivation years statistically significant difference was observed between the NTC-PAC and the other treatments. The parallel to the contour planting gave better results compared with the perpendicular to contour tillage, both in two years of experiments. Between the two cultivation years the proteins was better in the 2nd year. The highest increase was noticed in the CTC-PAC treatment (2%).

Table 3. Protein content of the *Helianthus annuus* cultivation in the 4 different soil practice treatments in the 1st growing year.

Treatment	Protein content, % *Helianthus annuus*		CV %
NTC-PAC	27.43	c	8.15
CTC-PAC	26.57	b	1.76
NTC-PEC	26.56	b	6.15
CTC-PEC	25.97	a	3.22
LSD		0.1642	

Table 4. Protein content of the *Helianthus annuus* cultivation in the 4 different soil practice treatments in the 2nd growing year.

Treatment	Protein content, % *Helianthus annuus*		CV %
NTC-PAC	27.72	a	6.75
CTC-PAC	27.00	a	2.25
NTC-PEC	26.94	a	8.55
CTC-PEC	26.09	a	4.31
LSD		0.1523	

Different letters at each column denote statistically significant difference of means according to the LSD test for 95% significance level ($p < 0.05$).

NTC-PAC: no tillage – planting parallel to the contour direction
CTC-PAC: conventional tillage – planting parallel to the contour direction
NTC-PEC: no tillage – planting perpendicular to the contour direction
CTC-PEC: conventional tillage - planting perpendicular the contour direction

2.6. N-uptake

Tables 5 and 6 show the N-uptake for the Sunflower as an under sown catch crop after pea cultivation in two studied years, respectively. The highest value of N-uptake was observed in no tillage, planting parallel to the contour (NTC-PAC). The 1st year the NUE ranged from 156 to 235 kg ha^{-1} and statistically significant difference was observed between NTC-PAC and NTC-PEC, CTC-PEC treatments. The 2nd cultivation year the N-uptake values ranged from 192 to 265 kg ha^{-1}. The results showed that between the NTC-PAC treatments and the other three ones there was statistically significant difference. In addition, an increase was noticed in 2nd year compared to 1st in all the treatments. In treatment NTC-PAC the increase was of a rate of 11%. At this point, it should be mentioned that according to the results the incorporation of pea residues can have positive effects to the increase of N-uptake over time.

Table 5. N-uptake of the *Helianthus annuus* cultivation in the 4 different soil practice treatments in the 1st growing year.

Treatment	N-uptake, kg ha-1 *Helianthus annuus*		CV %
NTC-PAC	235	c	2.76
CTC-PAC	222	bc	8.17
NTC-PEC	210	b	6.55
CTC-PEC	156	a	3.69
LSD		6.4528	

Table 6. N-uptake of the *Helianthus annuus* cultivation in the 4 different soil practice treatments in the 2st growing year.

Treatment	N-utake, kg kg-1 *Helianthus annuus*		CV %
NTC-PAC	265	c	9.15
CTC-PAC	231	b	2.45
NTC-PEC	217	b	7.65
CTC-PEC	192	a	4.55
LSD		4.5947	

Different letters at each column denote statistically significant difference of means according to the LSD test for 95% significance level ($p < 0.05$).

NTC-PAC: no tillage – planting parallel to the contour direction
CTC-PAC: conventional tillage – planting parallel to the contour direction
NTC-PEC: no tillage – planting perpendicular to the contour direction
CTC-PEC: conventional tillage - planting perpendicular the contour direction

3. Discussion

Our study showed that the plants' height was better in no tillage practice. Our results are in disagreement with the investigations [22, 23]. According to their study the plant height were higher in conventional tillage in comparison to no tillage cultivation. The height of plants were the first year from 85.2 to 64.9 cm and from 66.5 to 86.5 cm the second one. Other researcher observed that the plant height of Sunflower crop was higher than in our results [23, 24] (Mujeeb-ul-Haq et al., 2020). At this point we should mention that our experiments were conducted under different cultivation conditions, specifically under rainfed sloping field conditions.

Data from our study site indicate that the no tillage – planting parallel to the contour had the highest LAI content but between the 4 treatments there was no statistically significant difference. Mujeed-ul-Haq et al. [24] noticed similar LAI values with our findings when 110 kg N ha^{-1} applied in Sunflower cultivation. In other research the LAI reached a value of 5.13 and 5.37 in conventional (reduced) and traditional tillage, 90 days after sowing, respectively [23]. Furthermore, Aboudrare et al. [25] found that LAI was lower than our results using no tillage cultivation.

In our investigation, plants' total nitrogen ranged from 4.153% in NTC-PEC treatment to 4.388% in NTC-PAC the 1st year. The 2nd year the nitrogen values was higher than the 1st year. Murillo et al. [26] study found out that the total nitrogen content was from 0.76 to 3.48, lower values compared with our results.

In Addition, the no tillage management had positive effects in the protein values. Statistically significant difference was observed the 2nd year of cultivation. Scheiner et al. [27] in their study mentioned that the protein content was from 20.2 to 23.6%. In our investigation we found higher protein's values which indicated that the pea residues incorporating into the field can provoke a significant increase to protein content.

Regarding the N-uptake in the NTC-PAC treatment performed higher values compared to other practices. The N-uptake reached values of 235 and 235 kg ha^{-1} the 1st and 2nd year, respectively. The same results are mentioned by other studies [11, 28]. Findings of Lopez-Bellino et al. [29] showed that the no tillage positively impacted the N-uptake, in agreement with our results.

4. Materials and Methods

4.1. Study Area

A field experiment with sunflower cultivation was conducted in experimental station of the University of Thessaly (Larissa - Greece). The studied area which has a latitude of 39°37'30'' and a longitude of 22°22'51'', is located at an altitude of 80m above sea level. Its climate is characterized as Mediterranean with hot and dry summers as well as cold and wet winters.

4.2. Soil analyses

A soil sample of the field was taken from a depth of 0-30 cm from the surface using a steel sampler, before the sowing period, each autumn. Soil sample was transported to the laboratory, air-dried and was sieved through a 2-mm sieve. Soil was analyzed for pH (1:2.5 d. H_2O), electrical conductivity (1:5 d. H_2O), calcium carbonate ($CaCO_3$) using a calcimeter, the percentage (%) of sand, clay and silt using the Bouyoukos method, organic matter with Walkley – Black method, total nitrogen (Kjeldahl method), available soil P (Olsen method, analyzed with ammonium vanadomolybdate / ascorbic blue and measured in a UV spectrophotometer at 882 nm) and exchangeable K (1:10 at 1M CH_3COONH_4 pH 7, analyzed in a flame photometer). All the analyses were carried out according to Rowell [30].

The soil was a clay loam, with pH 8.21, organic matter between 1.6 - 1.65% and total nitrogen 0.08% the 1st year and 0.085% the 2nd. The physicochemical properties of the soil are presented in Table 7.

Table 7. Physicochemical properties of the used soil.

Cultivation year	pH	E.C. (μS cm^{-1})	CaCO3	Organic matter (%)	Total Nitrogen (%)	Olsen P (mg kg^{-1})	Exchangeable K (mg kg^{-1})	Sand (%)	Clay (%)	Silt (%)
2015	8.21	435	16.5	1.65	0.08	21.24	216.06	38.41	36.11	25.48
2016	8.1	454	15.6	1.6	0.085	6.8	198.5	39.63	36.5	23.88

4.3. Field experiment

A two – year field experiment was established in a field with a slope of 5%. The experimental design was a split plot. The treatments were: (a) no tillage cultivation - planting parallel to the contour direction (NTC-PAD), (b) conventional tillage cultivation - planting parallel to the contour direction (CTC-PAD) (c) no tillage cultivation - planting perpendicular to the contour direction (NTC-PED), (d) conventional tillage cultivation - planting perpendicular to the contour direction (CTC-PED). Each treatment had three replications. The plots were 132m^2 in size (6 m in width and 22 m in length). Planting arrangement was 75 x 20 cm, consisted of eight rows 75 cm apart and an average plant density for sunflower of 10 plants m^{-2}.

Before the sowing all the necessary cultivation practices were conducted. The residues of the previous autumn cultivation at a rate 30% - 70% (*Triticosecale x Pisum sativu*m) were incorporated in the field at the end of their biological cycle and about 20 days before the sunflower sowing. The mean total incorporated biomass of the intercropping was 2.4 and 2.63 t ha^{-1} the 1st and the 2nd sunflower growing year, respectively. The procedure of the residues decomposition was accelerated by the natural rainfall. Moreover, in conventional tillage plots were conducted ploughing to a depth of about 25 cm. Sowing dates and other agronomic data are summarized in Table 8.

Fertilization was applied during sowing as basal dressing using a compound fertilizer (N: 40 kg N ha^{-1}, P: 60 kg P_2O_5 h^{-1} and K: 60 kg K_2O ha^{-1}) in all plots. Furthermore, nitrogen was added in the soil from the previous cultivation (intercropping *Triticosecale - Pisun sativum*) due to the fix - N_2 from the atmosphere (Table 9). The plots were cultivated under rainfed conditions and this is due to the fact that the specific area is considered to be a dryland one.

Table 8. Agronomic data of sunflower cultivation.

	LARISSA	
	2015	**2016**
Incorporation date	8/06/2015	25/05/2016
Date of sowing	30/06/2015	12/06/2016
Date of flowering	20/8	10/8
LAI – SLA measurement	28/7, 27/8, 15/9	18/7, 16/8, 4/9
Date of harvest	17/10/2015	16/10/2016

Table 9. N uptake of intercropping *Triticosecale -Pisum sativum* cultivation (kg N ha^{-1})

Treatments	**2015**	**2016**
	kg N ha^{-1}	
NTC-PAC	93.71	101.57
CTC-PAC	86.72	91.79
NTC-PEC	66.76	71.31
CTC-PEC	49.89	52.81

4.4. Experimental Measurements

4.4.1. Plant height

Ten plants from every plot were randomly selected. Plant height was measured using a measuring tape, from ground level to the top edge of the inflorescence.

4.4.2. Leaf area index (LAI) - Specific leaf area (SLA)

To investigate LAI and SLA of sunflower plants, three plants of each plot were randomly harvested early in the morning. Three measurements of LAI and SLA were conducted, the 1st year in 28/7, 27/8, 15/9 and the 2nd year in 18/7, 16/8, 4/9. Leaf area index was determined using an automatic LI-COR (model LL-3000A). Specific leaf area Leaf area index was measured as the product of the green leaf area dry weight.

The connection between SLA and LAI indicated by the equation:

$$\mathbf{LAI = SL * SLA * 10^{-4}} \quad (1)$$

where SL is the dry weight of the fresh leaves (kgha^{-1}).

4.4.3. Total nitrogen – proteins in plants

The plant samples from each plot after the harvest were transported in the Lab and were remained in oven at 700C until constant weights. The total nitrogen content in the sunflower plants was calculated using the Kjeldahl method [31]. Total Protein content was measured in the dry grains by near-infrared reflectance (NIR) spectroscopy technique using the DA 7250 NIR analyzer (Perten Instruments, Hägersten, Sweden).

4.4.4. N-uptake

The measurement of N-uptake was performed using the below equation:

N-uptake = yield X plant' total nitrogen (2)

4.5. Statistical analysis

The experimental data was analyzed using the statistical package Statgraphics plus 8.1to the LSD test about the level of significance 95% ($p<0.05$).

5. Conclusions

In this research, we evaluated the impact of no-tillage on plant height, LAI, SLA, plants' nitrogen and proteins and of Sunflower in a rotation system with intercropping *Triticosecale – Pisum sativum* under natural rainfall in comparison to conventional agriculture. In addition, we tested the effect of planting direction (parallel and perpendicular to the contour).

The results showed that plant height was higher in no – tillage, planting parallel to the contour cultivation. LAI (3.69 the 1st year and 4.01 the 2nd year) gave the maximum values in NTC-PAC treatment. No tillage - planting parallel to the contour direction (NTC-PAC) treatment, also, impacted positively SLA values.

The total nitrogen and proteins of Sunflower plants were better the 2nd year of experiments and the highest increase was noticed in the CTC-PAC treatment (2%). Furthermore, the no tillage practice affected the N-uptake and both in two cultivation years.

To sum up, we come to the conclusion that, in a sloping dryland field the Sunflower can be a promising crop when cultivated in a rotation system with the intecropping *Triticosecae - Pisum sativum* using the no tillage – planting parallel to the contour processing under Greek climate.

The incorporation of leguminous residues into fields can increase significantly the nitrogen content and many abandoned sloping lands will be cultivated.

Supplementary Materials: Not applicable

Author Contributions: Conceptualization, A,M; methodology, A.M. and E.S.; software, G.C.; investigation, M.D. and E.S.; writing—original draft preparation, A.M. and E.S.; writing—review and editing, A.M.; supervision, A.M and K.S.; project administration, A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding

Data Availability Statement: Not applicable

Conflicts of Interest: The authors declare no conflict of interest

References

1. Fernández-Martínez, J,M,; Pérez-Vich, B.; Velasco, L. Sunflower. In: Vollmann, J., Rajcan, I. (eds) Oil Crops. Handbook of Plant Breeding. Springer, N, 2009; vol 4. https://doi.org/10.1007/978-0-387-77594-4_6.
2. Mohammadi, K.; Heidari, G.; Javaheri, M.; Rokhzadi, A.; Nezhad, M.T.K; Sohrabi, Y.; Talebi, R. Fertilization affects the agronomic traits of high oleic sunflower hybrid in different tillage systems. *Industrial Crops and Products.* **2012,** *44*, 446-451. https://doi.org/10.1016/j.indcrop.2012.09.028.
3. Meydani, S.N.; Lichtenstein, S.N.; White, P.J.; Goodnight, S.H.; Elson, C.E.; Woods, M.; Gorbach, S.L; Schaefer, E.J. Food use and health effects of soybean and sunflower oils. *Journal of the American College of Nutrition*. **1991,** *10(5*), 406-428. https://doi.org/10.1080/07315724.1991.10718168.

4. Akbari, P.; Ghalavand. A., Modarres Sanavy, A.M.; Alikhani, M.A. The effect of biofertilizers, nitrogen fertilizer and farmyard manure on grain yield and seed quality of sunflower (Helianthus annus L.). *Journal of Agricultural Technology*. **2011**, *7(1)*, 173-184.
5. Coêlho, E.D.D.; Souza, A.R.E.D.; Lins, H.A.; Santos, M.G.D.; Freitas Souza, M.D.; Lima Tartaglia, .D.; Oliveira, A.K.S.D.; Lopes, A.R.W.D.; Silveira, L.M.; Mendonça, V.; Júnior, A.R.B. (2022). Efficiency of Nitrogen use in Sunflower. *Plants*. **2022**, *11*, 2390. https://doi.org/10.3390/plants11182390.
6. Blanco-Sepúlveda, R.; Enríquez-Narváez, F., Lima, F. Effectiveness of conservation agriculture (tillage vs. vegetal soil cover) to reduce water erosion in maize cultivation (Zea mays L.): An experimental study in the sub-humid uplands of Guatemala. *Geoderma*. **2021**, *404*, 115336. https://doi.org/10.1016/j.geoderma.2021.115336.
7. Wolschick, N.H.; Bertol, I.; Barbosa, F.T.; Bagio, B.; Biasiolo, L.A. Remaining effect of long-term soil tillage on plant biomass yield and water erosion in a Cambisol after transition to no-tillage. *Soil and Tillage Research*. **2021**, *213*, 105149. https://doi.org/10.1016/j.still.2021.105149.
8. Pittelkow, M.C.; Liang, X.; Linquist, B.A.; van Groenigen, K. J.; Lee, J.; Lundy, M.E.; van Gestel, N.; Six, J.; Rodney, T.; Venterea, R.T.; van Kessel, C. Productivity limits and potentials of the principles of conservation agriculture. *Nature*. **2015**, *517*, 365–368. https://doi.org/10.1038/nature13809.
9. Giller, K.E.; Andersson, J.A.; Corbeels, M.; Kirkegaard, J.; Mortensen, D.; Erenstein, O.; Vanlauwe, B. Beyond conservation agriculture. *Front. Plant Sci*. **2015**, *6*, 870. https://doi.org/ 10.3389/fpls.2015.00870.
10. Tarolli, P.; Cavalli, M.; Masin, R. High-resolution morphologic characterization of conservation agriculture. *Catena*. **2019**, *172*, 846-856. https://doi.org/10.1016/j.catena.2018.08.026.
11. Zubillaga, M.M.; Aristi, J.P.; Lavado, R.S. Effect of Phosporus and Nitrogen Fertilization on Sunflower (Helianthus annuus L.) Nitrogen Uptake and Yield. *Journal of Agronomy and Crop Science*. **2002**, *188*, 267-274. https://doi.org/10.1046/j.1439-037X.2002.00570.x.
12. Rasool, K.; Wajid, A.; Ghaffar, A.; Shoaib, M.; Arshad, M.; Abbas. S. Optimizing nitrogen rate and planting density for sunflower under irrigated conditions of Punjab. *SAARC Journal of Agriculture*. **2015**, *13*, 174-187. https://doi.org/10.3329/sja.v13i1.24190.
13. Muhammad, M.U.H.; Mudassir, H.; Amjed, A.; Muhammad, A. Influence of nitrogen application on phenology, growth and yield of sunflower (Helianthusannuus L.). *Inter j Biosci*. **2020**, *17(2)*, 9-16. https://doi.org/10.12692/ijb/17.2.9-16.
14. Muhammad, I.A; Amjed, A.; Liang, H.; Abdul, L. Nitrogen effects on sunflower growth: a review. *Inter J Biosci*. **2018**, *12(6)*, 91-101. https://doi.org/10.12692/ijb/12.6.91-101.
15. Haugaard-Nielsen, H.; Ambus, P.; Jensen, E.S. (2001). Interspecific competition, N use and interference with weeds in pea barley intercropping. *Field Crops Research*. **2001**, *70(2)*, 101–109. https://doi.org/10.1016/S0378-4290(01)00126-5.
16. Miller, P.; Buschana, D.E.; Jones, C.A.; Holmes, J.A. Transition from Intensive Tillage to No-Tillage and Organic Diversified Annual Cropping Systems. *Agronomy Journal*. **2008**, *100*, 591–599 (2008). doi:10.2134/agronj2007.0190
17. Babec, B.; Seremesic, S.; Hladni, N.; Terzic, S.; Vojnov, B.; Cuk, N.; Gvozdenac, S. Effect of intercropping sunflower with legumes on some sunflower morphological traits. *Ratar. Povrt*. **2020**, *57(2)*, 61-67. https://doi.org/10.5937/ratpov57-23813.
18. Skoufogianni, E.; Danalatos, N.G.; Dimoyiannis, D.; Efthimiadis, P. Effects of pea cultivation as cover crop on nitrogen-use efficiency and nitrogen uptake by subsequent maize and sunflower crops in a sandy soil in Central Greece. *Comm. Soil Sci. Plant Anal*. **2013**. *44(1-4)*, 861-8. https://doi.org/10.1080/00103624.2013.749446.
19. Dang, Y.P.; Moody, P.W.; Bell, M.J.; Seymour, N.P.; Dalal, R.C.; Freebairn, D.M; Walker, S.R. Strategic tillage in no-till farming systems in Australia's northern grainsgrowing regions: II. Implications for agronomy, soil and environment. *Soil Tillage Res*. **2015a**, *152*, 115–123.
20. Peixoto, D.S.; Silva, L.D.C.M.D.; Melo, L.B.B.D.; Azevedo, R.P.; Araújo, B.C.L.; Carvalho, T.S.D.; Moreira, S.G.; Curi, N.; Silva, B.M. Occasional tillage in no-tillage systems: A global meta-analysis. *Science of the Total Environment*. **2020**, *745*, 14887.

21. Carretta, L.; Tarolli, P.; Cardinali, A.; Nasta, P.; Romano, N.; Masin, R. Evaluation of runoff and soil erosion under conventional tillage and no-till management: A case study in northeast Italy. *CATENA*. **2021**, *197*, 104972.
22. Sessiz, A.; Sogut, T.; Alp, A.; Esgici, R. Tillage effects on sunflower (*Helianthus annuus*, l.) emergence, yield, quality, and fuel consumption in double cropping system. *Journal of Central European Agriculture.* **2009**, *9*, 697-709.
23. Mourad, A.K.; Nawar, I.A.; Khalil, E.H. Sunflower Growth Performance under Tillage or no Tillage Practice, Irrigation Intervals and Nitrogen Fertilization Rates. *Alex. J. Agric. Sci.* **2020**, *65 (3)*, 223-232.
24. Mujeeb-ul-Haq, M.; Hassan, M.; Ali, A.; Adnan, M.; Asif, M.; Hayyat, M.H.; Khan, B.A.; Amin, M.M.; Raza, A.; Nazeer, S.; Manzoor, M.A.; Basit, A.; Ahmed, R. Influence of nitrogen application on phenology, growth and yield of sunflower (Helianthus annuus L.). *International Journal of Bioscience*s. **2020,** *17(*2), 9-16.
25. Aboudrare, A.; Debaeke, P.; Bouaziz, A.; Chekli, H. Effects of soil tillage and fallow management on soil water storage and sunflower production in a semi – arid Mediterranean climate. *Agricultural Water management*. **2006**, *83*, 183-196.
26. Murillo, J.M.; Mereno, F.; Pelegrin, F.; Fernandez, J.E. Responses of sunflower to traditional and conservation tillage under rainfed conditions in Southern Spain. *Soil & Tillage Research.* **1998,** *49*, 233-241.
27. Schneiner, J.D.; Gutierrez, F.H.; Lavado, S. Sunflower nitrogen requirement and 15N fertilizer recovery in Western Pampas, Argentina. *European Journal of Agronomy*. **2002**, *17*, 73-79.
28. Eltarabily, M.G.; Burke, J.M.; Bali, K.M. Effect of Deficit irrigation on Nitrogen Uptake of Sunflower in the Low Desert Region of California. *Water*. **2019**, *11*, 2340.
29. Lopez-Bellido, R.; Lopez-Bellido, L.; Castillo, J.E.; Lopez-Bellido, F.J. Nitrogen uptake by sunflower as affected by tillage and soil residual nitrogen in a wheat-sunflower rotation under rainfed Mediterranean conditions. *Soil and Tillage Research.* ***2003,*** *72 (1)*, 43-51.
30. Rowell, D.L. Soil science: Methods and applications. Longman Group UK Ltd,1994; London.
31. Bremner, J.M.; Mulvaney, C.S. "Total nitrogen", In: A.L. Page, R.H. Miller and D.R. Keeny, (Eds.), Methods of Soil Analysis, American Society of Agronomy and Soil Science Society of America, Madison, 1982; pp. 1119-1123**.**