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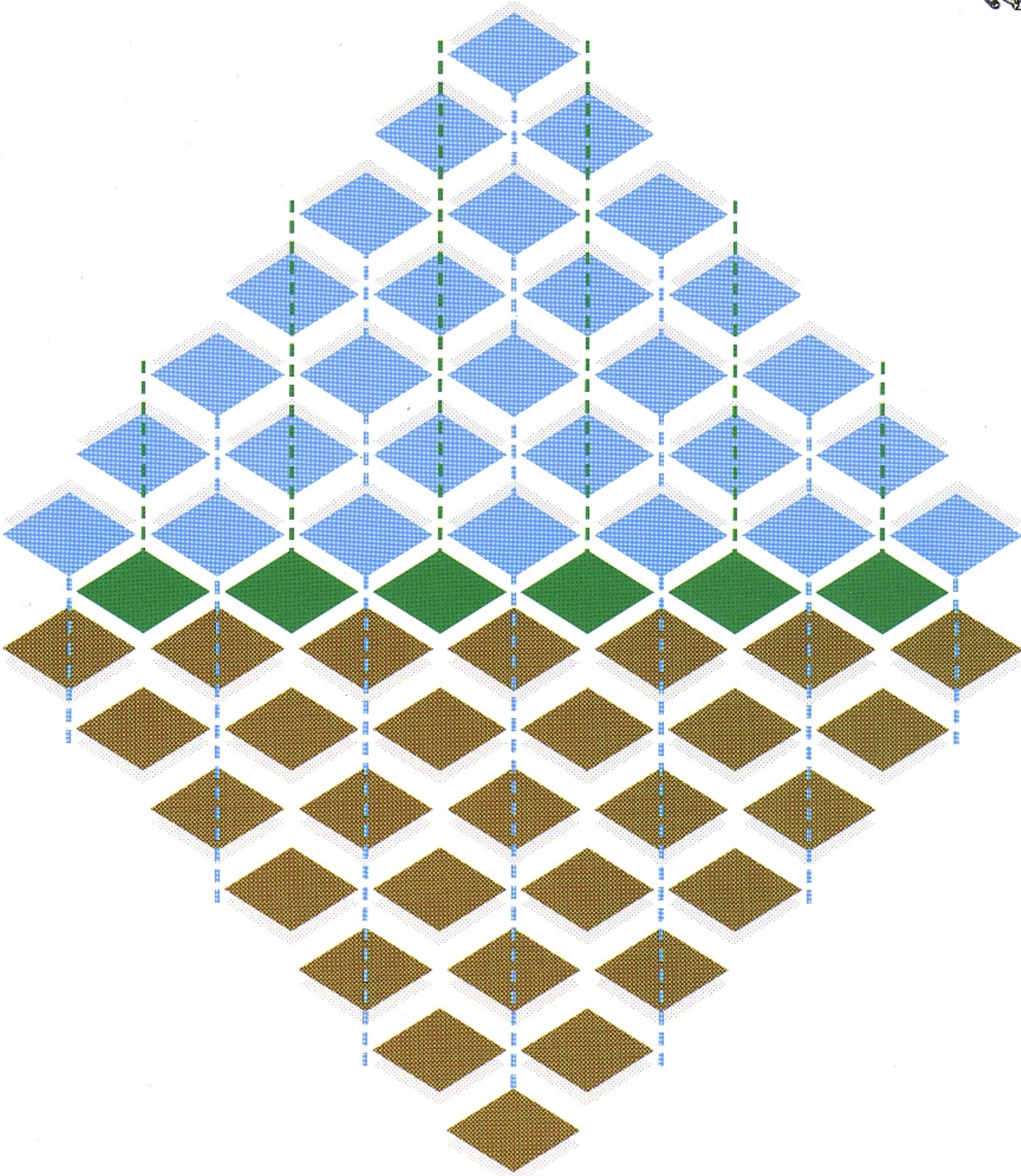

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Contribution of Soil to CO_2 Balance in Industrial Oil Crops

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ABSTRACT

BACKGROUND. Cultivation of oilseed crops for energy production (methylester) leads to a positive energy balance, as found for sunflower and rapeseed in crop rotations typical of Northern Italy. In these crops, a positive CO_2 balance has also been calculated, thus allowing possible mitigation of the greenhouse effect. Despite this, very little is known on the evolution of CO_2 from cultivated soils, and the wide variability of data found in the literature greatly depends on the farming system. It is therefore necessary to find the most suitable type of agricultural management (input level) to optimise the CO_2 balance.

METHODS. In this paper, some results of CO_2 balances are presented, for sunflower and rapeseed used for biodiesel production, based on data derived from a survey of 400 cultivations in the Veneto Region (Po valley – North-East Italy). The dynamics of CO_2 fluxes were simulated over a two-year period, and the contribution of soil in the balance was estimated with a new model (DiSOS, Dynamics of Soil Organic Matter) which takes into account the evolution of this gas from soils as a function of tillage.

RESULTS. Analyses revealed the relative weight of tillage intensity and the amount of crop residues in maintaining the soil carbon balance. The amount of crop residues, produced by the oilseed crops considered here, turned out to be the main factor.

CONCLUSIONS. The DiSOS model was very useful in estimating the dynamics of the soil carbon balance as a function of cropping system, and contributed towards estimating the CO_2 balance of oilseed crops. Sunflower showed more stable behaviour in the various cropping systems, providing both reasonably good yields and CO_2 storage even with low inputs, with associated higher energy efficiency than rapeseed. Instead, rapeseed gained more from high input levels in terms of amount of carbon storage, but was more sensitive to extensive management as regards energy efficiency.

Key-words: carbon dioxide balance, energy inputs, modelling soil organic carbon, rapeseed, sunflower.

INTRODUCTION

One of the main goals of substituting fossil fuels with renewable resources is to reduce emissions of greenhouse gases (e.g., carbon dioxide). When dealing with the production of raw materials from plants for energy purposes, this concern is very relevant because, on the one hand there are fewer new CO_2 emissions, due to the substitution of fossil products and, on the other, plants can store CO_2 in their biomass by photosynthesis, thus subtracting this gas from the atmosphere.

An important natural stock of energy is wood, due to its highly differentiated uses and applications. These include energy production, construction materials and furniture. Especially for the latter, substantial subtraction of CO_2 from the atmosphere is expected, because of the long life of these products – in some cases virtually forever (Post et al., 1990; Johnson and Kern, 1991; Kern and Johnson, 1993; Gregory et al., 1996; Lal and Kimble, 1997).

In addition to wood, there are other very interesting carbon-storing productions. For instance, oils derived from oilseed crops can mitigate the greenhouse effect (Riva, 1992), their applications being different from traditional food uses, e.g., fuels, lubricants, plastic films and paints for vehicles (Auld et al., 1989; Banat, 1995; Honary, 1996; Lazzeri and Malaguti, 1996).

Since the use of these oils is now becoming quite widespread, it is essential to understand clearly which environmental issues are associated with the cultivation of oilseed crops, especially as regards the amount of fixed CO_2. Mosca and Bona (1999) presented some preliminary results on CO_2 balances in rapeseed and sunflower for biodiesel production, assuming that the amount of organic matter in the soil remains constant. Their assumption may be considered realistic if a steady-state condition for soil tillage is verified. The same authors also showed that, although the amount of CO_2 immobilized by rapeseed and sunflower cannot be modelled as a function of input level because of the large variability of data, the maximum energy efficiency in CO_2 storage can be reached by choosing low-input farming systems. However, under such management, organic matter oxidization in soils, as well as the amount of crop residues to be incorporated into the soil, can be expected to fall, so that possible variations in the soil carbon balance associated with variations in crop management should be further investigated.

In this paper, some results on the CO_2 balances of two oilseed crops, rapeseed and sunflower cultivated in North-East Italy, are presented. A new model, introduced to estimate the dynamics of organic matter in soils, was also used to identify the most suitable agricultural management to be adopted for achieving maximum CO_2 storage in soil.

MATERIALS AND METHODS

The CO_2 balance was calculated from data obtained in a survey in the Veneto Region (North-East Italy), regarding cultivation of rapeseed and sunflower, 400 in all, for biodiesel production. From each farm, information based on questionnaires was gained on the cropping system.

In the first part of this work, the overall CO_2 balance was estimated as the difference between storage (fixing by the crop) and carbon emission, without considering the contribution of the soil.

CO_2 emission (i.e., the negative part of the balance), due to the use of cropping inputs (e.g., fuels and lubricants, seeds, fertilizers, chemicals, construction of machinery for cropping operations) and those involved in the post-harvest phases (e.g., grain transport, drying and crushing, oil esterification) were computed using coefficients of conversions from the literature (e.g., Börjesson, 1996; Pimentel, 1980). All crop inputs, both direct and indirect, were also converted into energy costs using specific energy coefficients (e.g., Cantele and Zanin, 1983; Fluck and Baird, 1980; Peterson et al., 1997).

The amount of carbon stored in the crop biomass (i.e., the positive part of the balance) was converted into CO_2 equivalents for each of its components and derived products (crop residues, methyl ester, oilcake/meal), thus allowing the fate of single fractions of carbon to be followed over time on an annual basis.

As a second step, the contribution of soil to the CO_2 balance in the two crops was estimated as a function of tillage input and grain yield, using a new model of CO_2 evolution from soil (DiSOS, Dynamics of Soil Organic Matter). Among various interpretations of the dynamics of organic matter in soil, it was considered that, in a stable ecosystem (steady-state condition) the amount of organic matter in soil remains constant over time (Buyanovsky et al., 1986). According to this assumption, if a steady-state condition is verified when a standard cropping system is used, then a normal tillage depth, which makes the released carbon equal to that incorporated by the crop on an annual basis, can be defined. Thus, tillage intensity was evaluated through the coefficient *Xsoil*, given by the ratio between the sum of the depths of each tillage operation (e.g., ploughing, grubbing, harrowing) applied to the considered crop, and the sum of the depths of each tillage operation in a standard farming system in the Veneto Region. In this ratio, the normal tillage depth (i.e., that commonly practised) derived from all the crops in this Region weighted on their surface area (data source: ISTAT 2002).

Estimation of organic matter breakdown in soil followed the algorithms proposed by Paustian et al. (1992).

RESULTS AND DISCUSSION

The model used here allowed the fate of CO_2 stored in each component of the crop biomass to be followed over time. As an example, Figure 1 shows the CO_2 evolution in rapeseed. The gross CO_2 balance is divided into independent contributions due to the different components, each of which presents a specific dynamic in relation to its duration: although all components contribute to the balance to a certain extent, their impact is closely related to their duration.

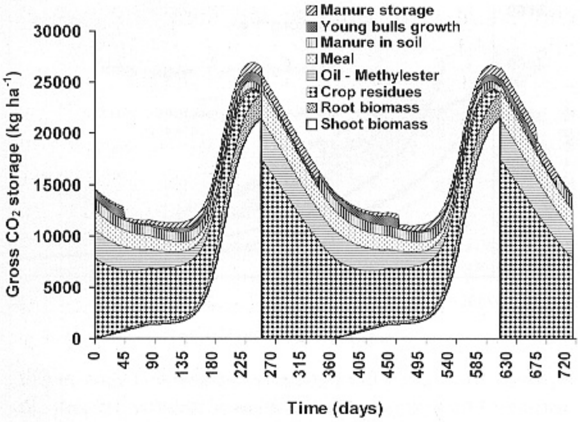

Figure 1. Simulation of gross CO_2 evolution for each component of biomass and derived products in rapeseed over a 2-year period, without considering soil contribution. Model takes into account use of meal for animal feed and manure distribution on the farm.

Obviously, the best product for storing CO_2 should have a very long duration (e.g., wood), but even for oilseed crops there are some relevant products. For instance, oilcake/meal can last one year, since they are normally used for animal feed prior to the next grain harvest. In this case, excluding that part of the carbon which is lost immediately (manure, rumination gases), the rest is stored in the animal tissues and afterwards incorporated in the human body by eating their meat. The analysis was stopped at a certain level of accuracy, because excessive complication of the model gives no further increase in precision, but may in fact lead to some mistakes. Therefore, in these calculations, the CO_2 stored in the human body was not taken into account.

An important store of carbon is represented by soil organic matter, actively implicated in soil-atmosphere CO_2 fluxes, which should be carefully considered. A rough calculation of the amount of organic carbon in a soil with 2% organic matter allows us to estimate an immobilization value of around 250000 kg ha^{-1} of CO_2 in the 0-40 cm depth. A problem arises, as variations in soil carbon balance due to crop residues are generally negligible. Considering the above example, the amount of crop residues produced by rapeseed (see Figure 1) and incorporated into the soil corresponds to around 18000 kg ha^{-1} of CO_2. This represents around 7% of the total CO_2 soil storage, but may accumulate over several years.

If the soil carbon storage were not considered, the situation given in Figure 2 would occur, a negative net CO_2 balance being possible in some cases, especially for high levels of CO_2 emission. The net CO_2 storage (outputs – inputs) in sunflower tended to decrease as CO_2 emission increased, because the amount of CO_2 stored in the various products is fairly stable with the input levels.

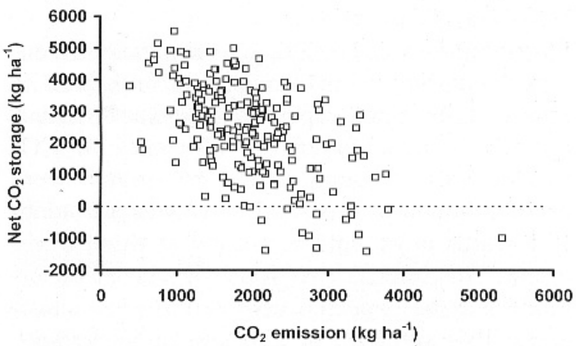

Figure 2. Net CO_2 storage as a function of CO_2 emission in sunflower, without considering soil contribution to the balance. Results from a survey of 400 farms in Veneto Region.

The farmers' main concern is profit, and this is directly related to energy input. The data presented in Figure 3 show the lack of any exact relationship between energy input (i.e., variations in the farming system) and amount of CO_2 storage (gross values). This highlights the substantial indifference of CO_2 accumulation to variations of input levels in both considered crops, thus allowing farmers to save money by

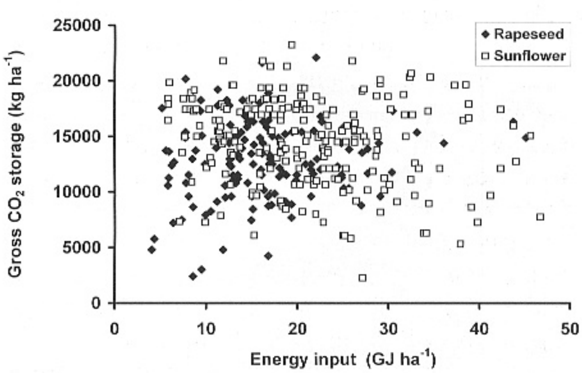

Figure 3. Gross CO_2 storage as a function of energy input in rapeseed and sunflower, without considering soil contribution to the balance. Results from a survey of 400 farms in Veneto Region.

reducing input levels substantially without markedly reducing CO_2 storage.

In order to optimise the input level to maximise the energy efficiency of CO_2 storage, the following ratio was considered:

$$EE_{CO2} = \frac{CO_2 \text{ stored in the system } (kg\ ha^{-1})}{\text{Energy inputs } (GJ\ ha^{-1})}$$

defined as the energy efficiency in carbon dioxide storage ($EECO_2$), as kg of CO_2 stored per GJ of energy used.

Plotting the values of EE_{CO2} versus those of energy inputs gives the distribution presented in Figure 4. In both rapeseed and sunflower, a marked increase in energy efficiency in CO_2 storage was obtained when low inputs were used, although in rapeseed there was a tendency towards more data scattering at these lower inputs. This implies that some degree of uncertainty may be expected with extensive management. This situation is well-known to farmers, because rapeseed is generally considered more sensitive – in terms of yield – than sunflower to reduced inputs, as shown in Figure 4.

If a regression between EE_{CO2} data and input level is done (logarithmic model) (Figure 5), sunflower presents a curve much closer to the boundary line (Webb, 1972; Schung et al., 1992) than rapeseed. This result implies that, beyond a given amount of CO_2 storage, lower energy efficiency for CO_2 storage must also be expected in rapeseed than sunflower, when low input levels are applied.

The main aim of this work was to verify the effects of tillage intensity on CO_2 storage in the soil. Although wide data variability – annual soil

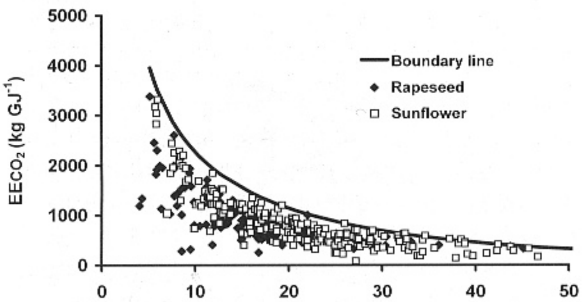

Figure 4. Energy efficiency in CO_2 storage ($EECO_2$) as a function of crop inputs in sunflower and rapeseed, and "boundary line". Data refer to a survey of 400 farms in Veneto Region.

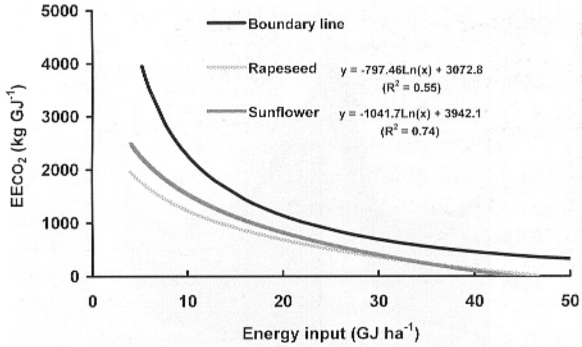

Figure 5. Regression lines of energy efficiency values in CO_2 storage ($EECO_2$) (see Figure 4) as a function of crop inputs, and "boundary line".

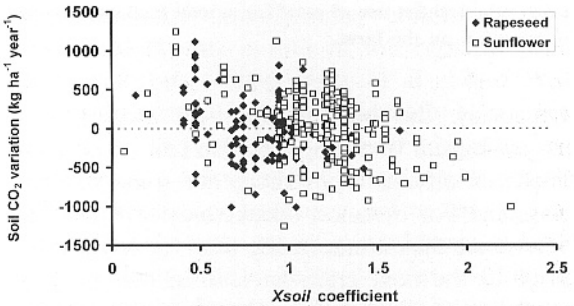

Figure 6. Effect of tillage intensity (expressed as increasing values of *Xsoil* coefficient) on annual variations in soil CO_2 storage.

CO_2 variations – was observed (Figure 6), the DiSOS model allowed us to identify only a slight decrease in CO_2 storage as a function of the *Xsoil* coefficient (i.e., with increasing tillage intensity). This indicates that some other factors, different from tillage, are acting. Comparisons between the two crops show that, at least in the present survey, there was higher tillage intensity in sunflower. Since the inputs were almost similar in the two crops (see Figure 3), this means that lower levels of the other inputs (e.g., fertilization) were applied to sunflower than rapeseed.

The DiSOS model revealed that, among others, crop yield was the main factor affecting CO_2 storage in soil. The linear regressions found between annual CO_2 variations in soil and yield had very high coefficients of determination (R^2), being around 0.87 in both rapeseed and sunflower (Figure 7). These equations were used to calculate the lowest yield which could induce

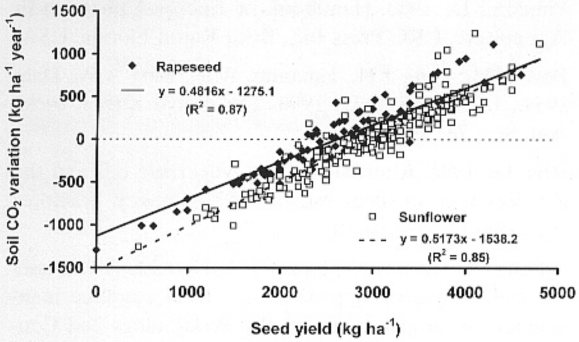

Figure 7. Annual variations in soil CO_2 storage as a function of grain yield in two oilseed crops. Rapeseed: filled diamonds and continuous regression line; sunflower: open squares and dashed regression line.

a positive net CO_2 storage in the soil in each crop, by identifying the intersection point of the lines with the X axis. For rapeseed, this value was 2647 kg ha^{-1}, which is very similar to the average yield in the survey (2665 kg ha^{-1}). For sunflower, the lowest yield for this purpose was 2666 kg ha^{-1}, also very similar to the average yield in the survey (2693 kg ha^{-1}). Since for both crops the average surveyed yield was slightly higher than the lowest required yield, a mean positive storage of CO_2 in the soil, albeit minimal, was expected. For sunflower, 58% of farms obtained increased CO_2 in soil, and 51% for rapeseed.

CONCLUSIONS

The DiSOS model was very useful in estimating the dynamics of the soil carbon balance as a function of cropping system, and contributed towards estimating the CO_2 balance of oilseed crops.

In both rapeseed and sunflower, low inputs led to a marked increase in the energy efficiency in CO_2 storage, although with the risk of causing a negative soil carbon balance. Simulations based on the survey showed that almost 45% of farms (rapeseed and sunflower together) were lowering the soil organic carbon balance, and the average yield only gave a slightly positive net CO_2 storage in soil.

However, some distinctions should be made between the two crops. Sunflower showed more stable behaviour in the various cropping systems, providing both reasonably good yields and CO_2 storage even with low inputs, with associated higher energy efficiency than rapeseed. Instead, rapeseed gained more from high input levels in terms of amount of carbon storage, but was more sensitive to extensive management as regards energy efficiency.

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IL CONTRIBUTO DEL SUOLO NEL BILANCIO DELLA CO_2 IN COLTURE INDUSTRIALI DA OLIO

Scopo. La coltivazione di colture da olio a fini energetici (metilestere), come girasole e colza, conduce ad un bilancio energetico positivo, come rilevato nelle rotazioni tipiche del Nord Italia. In queste colture anche il bilancio della CO_2 è risultato positivo, suggerendo la possibilità di mitigare l'effetto serra l'utilità con la loro coltivazione. Tuttavia, le conoscenze sull'evoluzione della CO_2 nei terreni coltivati sono ancora scarse. Risulta necessario quindi, individuare i livelli di input più adeguati per ottimizzare il bilancio della CO_2.

Metodo. In questo lavoro vengono presentati i risultati preliminari del bilancio della CO_2, nelle colture di colza e girasole destinate alla produzione di biodiesel, basato su un'indagine campionaria svolta presso 400 aziende agricole dislocate in Veneto (Pianura Padana – Nord-Est Italia). La dinamica dei flussi di CO_2 è stata simulata nell'arco temporale di un biennio, ed il contributo del suolo nel bilancio è stato stimato attraverso un nuovo modello (DiSOS, Dinamica della Sostanza Organica del Suolo) che stima l'evoluzione della CO_2 dal suolo in funzione dell'intensità di lavorazione del terreno.

Risultati. I risultati ottenuti indicano che entrambi i fattori considerati, intensità di lavorazione del terreno e quantità di residui colturali, influenzino l'entità degli scambi di carbonio suolo/atmosfera. Tra i due, tuttavia, la quantità di residui colturali è risultata essere determinante per massimizzare l'immagazzinamento di carbonio organico nel terreno, sottolineando così l'importanza di raggiungere elevati livelli di fitomassa.

Conclusioni. Il modello DiSOS si è rivelato molto utile nello stimare la dinamica del bilancio del carbonio del terreno in relazione al sistema colturale impiegato. Il girasole ha manifestato un comportamento più stabile nei diversi sistemi colturali allo studio, fornendo allo stesso tempo rese accettabili e discreta capacità di immagazzinare la CO_2 atmosferica anche in condizioni di basso input, comportamento raggiunto con una efficienza energetica superiore rispetto al colza. Quest'ultimo, al contrario, si è maggiormente avvantaggiato in sistemi colturali ad alto input in termini di carbonio immagazzinato, ma è risultato più sensibile alle tecniche di gestione relativamente all'efficienza energetica.

Parole chiave: bilancio dell'anidride carbonica, input energetici, simulazione delle variazioni del carbonio organico del suolo, colza, girasole.