Carbon footprint of rainfed and irrigated crops under tillage compared to no till & guide assistance

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Abstract

One of the most important key points for agriculture in the next years is to reduce its impact over the climate change (CC). This work try to demonstrate which crops, soil and water management systems are more profitable in order to reduce the contribution of agriculture to CC.

This work shows the results of 1 season carried out in Southern Spain. Different crops were studied in rainfed and irrigated conditions. Two soil management systems were compared: Tillage (T) versus No Till (NT) & Guide Assistance (GA). For irrigated crops two water supplies were studied. The parameters on mechanized operations were logged using a remotely data acquisition system. The equivalent Carbon Dioxide (CO_2) emitted was calculated by an energy analysis. The CO_2 fixed was a transformation of the yield. Two indicators were defined, CO_2 Efficiency (CE). Carbon Productivity (CP).

Irrigated yields in corn doubled the production of cereals and were nearly 10 times bigger than beans, especially for higher irrigation. There were no differences between T and NT&GA, except for wheat. The CO_2 emitted in T always were more than a 20 % higher than NT&GA. This situation caused that NT&GA always provided best results of CE and CP. Barley under NT&GA obtained the higher values of CE (3,7) and CP (3,6) due to the scarce use of fertilizers. Corn with sustainable techniques produced better results than wheat. However, for T this crop had lower values than wheat under NT&GA.

Keywords: arable crops, conservation agriculture, controlled traffic, energy used, climate change

1. Introduction

Andalusia, located in the South of Spain, is one of the main agricultural producers of this country. This region accounts aproximatly a 21 % of the total agricultural area of Spain, around 17 M ha (Spanish Government, 2016). The rainfed arable crops represent a 36.7 % of the Andalusian countryside and the irrigated crops a 7.2%, occupying between them more than 1.5 M ha. The climate of region is typically Mediterranean, especially sensitive to the changes produced by climate change (CC) (Moss et al., 2010; Iglesias et al., 2012), induced by human activity (UNFCCC, 1992; IPCC, 1995). Rising temperatures(IPCC, 2014) and the more intense and frequent extreme weather events such as floods and storms and long periods of absence of rain (Sousa et al., 2011) will cause an increase in irrigated crops (Savé et al., 2012) and loss of arable land in these areas most affected by the adverse effects of CC.

Agriculture is the third human activity in green houses gasses emissions (GHG), with about a 10 % of the total. It is especially important in the emissions of Nitrous oxide (N_2O) and Methane (CH_4), 79% and 52% respectively. Globally agriculture is responsible for 30% of the total emissions of Carbon dioxide (CO_2) N_2O and CH_4 (Denman et al., 2007; Popp et al., 2010; Srinivasarao et al., 2015).

In order to maintain the agrarian production in these regions and adapt and reduce the influence of CC, it is necessary to implement techniques that allow improving the carbon (C) balance of the crops.

The use of conservation agriculture techniques for arable crops, No till (NT), have widely demonstrate to decrease the emissions and the use of C in many regions of the world (Kassam et al., 2012; Lal, 2014). The suppression of the soil tillage produces an important reduction of the fuel consumption and the number of farming operations (Holland, 2004; Sánchez-Girón et al., 2004; Triplet & Dick, 2008; Gil-Ribes et al., 2014).

Guide assistance (GA) systems that allow a more efficient and homogeneous work and optimize the farming operations (Perez-Ruiz et al., 2012; Vellidis et al., 2013) produce a reduction of the overlaps and consequently a decrease of the use of agricultural inputs (Aernhammer, 2001; Borch, 2007).

Finally, in irrigated crops an important amount of energy is used in the water supply (Rodríguez-Díaz et al., 2009; Fernández-García et al., 2016). The applications of techniques which optimize the use of water, according to the real necessities of the crops, reduce it use and decrease the necessities of energy (Daccache et al., 2014; Tarjuelo et al., 2015) and consequently the emissions of CO_2.

However, the change of soil management system, not only could produces differences in the emissions, but also could bring a variation in yields (Gil-et al., 2014; Pittelkow et al., 2015) and also increased the use of some inputs, as herbicides (Sánchez-Girón et al., 2007). Furthermore, the application of irrigation increases the use of C but also enhance the yields respects rainfed productions (Nassi o Di Nasso et al., 2011).

So the objectives of this work were:

1) Study the yield variation of arable crops managed with NT and tillage (T) in rainfed and irrigated conditions.

2) Study the savings that NT & GA could bring respect to T, referencing to the C emissions.

3) Study the C balance of different crops under rainfed and irrigated conditions in order to optimize the C use.

2. Materials and Methods

2.1. Experimental Fields

This work belongs to a European project, Life + Climagri, and it shows the results of one season carried out in on representative farm of the Andalusian countryside: Experimental Farm of Rabanales, Cordoba (Field 1), 37º 55’ 50’’ N 4º 43’ 07’’ W; located closed to the University Campus, figure 1.

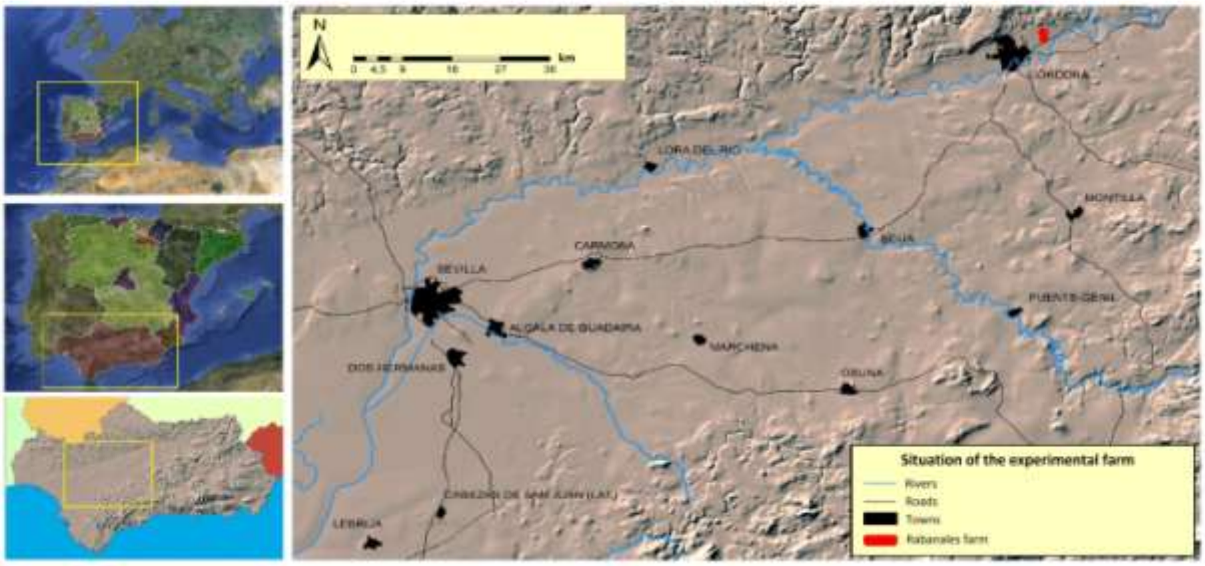

Figure 1. Location of the experimental field.

The Mediterranean region, where the study area is located, corresponds to a xeric moisture regime, according to the standards established by the Soil Taxonomy (USDA, 1998). The temperature regime is termic, and the climate has two opposite periods: one cold and wet during the fall and winter, and another warm and dry during spring and summer. During the last one the crops suffer an important water deficit. Furthermore, the precipitations are quite variable throughout the year and between them.

In the experimental farm 40 hectares of rainfed and irrigated arable crops were cultivated under two soil management systems (T and NT supported by GA). Trials, in each management system, had a typical crop rotation of the Andalusian countryside for rainfed conditions: cereal, sunflower and legume, and maize and cotton for irrigated. However this first season just winter wheat, beans, maize and barley were sown. Agronomically, farms were conducted according to the landowners’ guidelines.

In the irrigated conditions, two water supplies were studied: the normal one used by the farmers, 750 mm ha^{-1}, and another that optimized the use of water by applying the real necessities of water of the crops, according to its vegetative state and the weather conditions (550 mm ha^{-1}).

2.2. Instrumentation used and field work

The field tasks were remotely logged by monitored the tractor: John Deere 6420 (82.5 kW). The instrumentation installed in the tractor is described in figure 2.

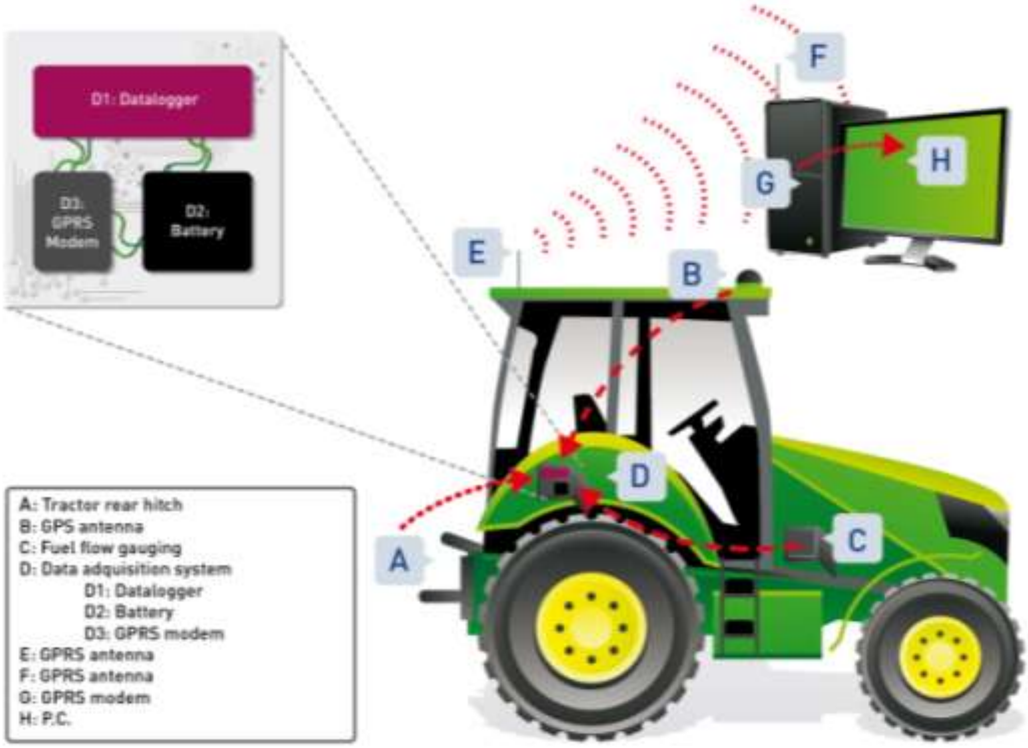

Figure 2. Scheme of the instrumentation installed in the tractor.

Each sensor installed in the tractor (A, B, C) allowed studying different parameters of the field tasks carried out to the crops. The potentiometer (A) model JX-PA-30-N14-21S, Unimeasure (Corvallis, USA), was used to detect the position of the tractor rear hitch, which indicated if the tractor was working in the field or was making a turn or in transport. The GPS, model GM-48 UB, Sanav (Taipei, Taiwan), was applied to the calculation of the time duration of a task; surface worked; average speed; theoretical work capacity; real work capacity; overlap. Finally, the flow meter (C), model AIC-4008 Veritas, AIC SYSTEMS AG (Allschwil, Switzerland), was used to measure the fuel consumption of each field task.

Complementary, the tractor had installed a guide assistance system, AgGPS EZ-Guide 500, Trimble (Sunnyvale, CA, USA), for spraying and fertilization, and an autopilot, EZ-Steer, Trimble (Sunnyvale, CA, USA), for seeding.

As data acquisition system was used a data logger (Data Taker DT 85, (Thermo Fisher Scientific, Australia)), which allows to record and transmit 48 signs, both digital and analog. Storing up to five million data. The system was programmed to record the following information, every two seconds,:

1. Geographical coordinates
2. Heading
3. Speed
4. Instant fuel consumption
5. Position of the tractor rear hitch

Automatically, every day, a server installed on a PC remotely connects with the data acquisition system, transmitting the data to the PC via GPRS, though a modem, ETM9560-1, Mäternick (Bromma, Sweden).

The average yield was studied by mapping the crops production. The fields were divided with a Pocket PC with EZ Maps software Trimble (Sunnyvale, CA, USA) in 10 plot of 0.5 ha. Samples of 1 m^2 were taken in the middle of the plot, repeating two times this operation in each sample zone. The production of each experimental unit was obtained by performing a simple average of the 10 sampled points.

As a complement, the incidents occurred during the work and other aspects such as dose of inputs (seeds and agrochemicals) were noted or reported.

2.3. Office work

From these data, using specific software "*Reporter Life*" developed in Basic language for this project, we studied each individual field task, determining the different indicators in the two systems analyzed. The program with the manually configuration of the implement width and the field surface, automatically calculated the following parameters:

1. Average speed
2. Average Fuel consumption
3. Theoretical work capacity
4. Real work capacity
5. Overlap
6. CO_2 emissions

The CO_2 emissions of each farming task was calculated by a previous energy analysis, transforming the energy used to equivalent CO_2 ($CO_{2\ equivalent}$) by multiplying by the factor (1 MJ=74 g CO_2 equivalent) described by Lal, 2004. The methodology used in the energy analysis was the proposed by the International Federation of Institutes for Advanced Studies (IFIAS). It associates the amount of non renewable energy to each of the factor of a process (Hernanz, 2005) (1). It defines two types of energy: direct-use energy; related to the consumption of fuel (2). This indicator was calculated multiplying the fuel consumption by 38.6 MJ l^{-1}. This value is referred to the lower heating value of fuel (46.000 kJ kg^{-1}) and its density (δ = 0.84 kg l^{-1}). The other type is the indirect-use energy (3); related to manufacture and maintenance of mechanical equipment, seeds, fertilizers and agrochemicals.

$$\text{Energy Consumed (MJ ha}^{-1}\text{) = Direct-Used Energy (MJ ha}^{-1}\text{) + Indirect-Use Energy (MJ ha}^{-1}\text{)} \quad (1)$$

$$\text{Direct-Used Energy (MJ ha}^{-1}\text{) = Annual crop fuel consumption (l ha}^{-1}\text{) * 38.6 MJ l}^{-1} \quad (2)$$

$$\text{Indirect-Use Energy (MJ ha}^{-1}\text{) = Energy used (MJ ha}^{-1}\text{) in: manufacture and maintenance of mechanical equipment + seeds + fertilizers + agrochemicals} \quad (3)$$

After the transformation of energy into $CO_{2\ equivalent}$, two main indicators can be developed: CO_2 Efficiency (CE). Defined as the ratio between the $CO_{2\ equivalent}$ contained in the final product (CO_2 Produced) by the required to cultivate it (CO_2 Consumed) (4). Carbon Productivity (CP). Defined as the amount of product produced (kg ha^{-1}) per unit of CO_2 supplied (kg ha^{-1}) (5).

$$CE = \frac{CO2\ Produced\ (Kg\ \text{ha}^{-1})}{CO2\ Consumed\ (kg\ \text{ha}^{-1})} \quad (4)$$

$$CP = \frac{Yield\ (kg\ ha^{-1})}{CO2\ Consumed\ (MJ\ \text{ha}^{-1})} \quad (5)$$

2.4. Statistical analysis

The statistical analysis of the data was developed with the software Statistix 8.0, Tallahassee, USA. The Tukey test was used to make the comparisons of means using a significance value (p) $\leq$ 0.05.

3. Results and Discussion

In the first season of study, there were no differences between the yields of NT and T, except for wheat, crop that produced more than 800 kg ha^{-1} under sustainable techniques. Barley just was seeded with NT, which is the reason of no data are shown for T. Irrigation crops (maize) doubled the production of cereals and were nearly 10 times bigger than beans, especially for higher irrigation.

Figure 3. Average yield for the different crops and management studied. Different letters show statistical differences for Tukey Test p≤0.05.

NT & GA reduced for all the crops the $CO_{2\ equivalent}$ emissions respect T. The lower reduction was obtained for wheat (16.5%, 237.7 kg $CO_{2\ equivalent}$ ha^{-1}). The next crop was maize with high irrigation and subsequently maize low irrigation (19.9 %, 599.1 kg $CO_{2\ equivalent}$ ha^{-1}; 21.5%, 599.0 kg $CO_{2\ equivalent}$ ha^{-1} respectively). The higher reduction was measured in legume (29.5%, 154 kg $CO_{2\ equivalent}$ ha^{-1}). These values were higher to those obtained by Moreno et al. (2011) in similar conditions. In legumes the emissions were low because they used few fertilizers, been NT the main technique to save CO_2 emissions. In the crops with a high used of fertilizer (wheat and maize) most of the reduction were brought by GA, as described Antle and Olge (2012) and Antille et al. (2015). Finally the used of water it was not as important as fertilization (Daccache et al., 2014).

Table 1. $CO_{2\ equivalent}$ emissions for the different crops and management studied.

	$CO_{2\ equivalent}$ Emissions (Kg ha^{-1})							
	SMS	Fuel	Maintenance	Seeds	Agrochemicals	Fertilizers	Irrigation	Total
Wheat	NT & GA	72.3	22.4	196.7	68.1	845.3	-	1,204.8
	T	126.8	39.3	204.6	42.4	1,029.4	-	1,442.5
Beans	NT & GA	67.1	20.8	140.4	113.4	26.2	-	368.0
	T	157.1	48.7	148.6	87.0	80.6	-	522.0
Barley	NT & GA	72.3	22.4	141.1	92.8	453.0	-	781.5
Maiz Low Irrigation	NT & GA	69.1	21.4	31.2	37.4	1,426.8	602.4	2,188.3
	T	198.0	61.4	32.1	39.2	1,854.4	602.4	2,787.3
Maiz High Irrigation	NT & GA	69.1	21.4	31.2	37.4	1,426.8	821.4	2,407.3
	T	198.0	61.4	32.1	39.2	1,854.4	821.4	3,006.4

The CO_2 efficiency and CO_2 productivity were always significantly higher for NT & GA respect to T, similar to the data obtained by Hernanz et al. (1995); Sartori et al. (2005) and Moreno et al. (2011), comparing NT and T in Mediterranean conditions.

Legumes showed the lower values of efficiency and productivity, despite being the crops with higher percentage of reduction, because their very low yield. The higher values were obtained in barley with sustainable systems; however, no data were obtained for T. The irrigated crops showed similar results for both indicators. The efficiency was higher respect to wheat; however this crop presented a higher productivity with NT & GA.

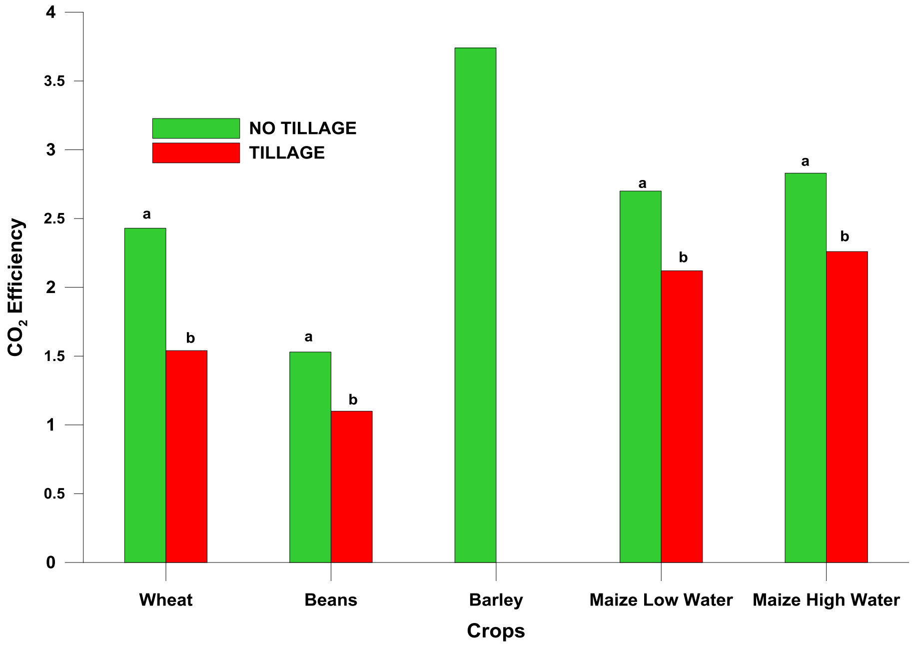

Figure 4. CO_2 efficiency for the different crops and management studied. Different letters show statistical differences for Tukey Test p≤0.05.

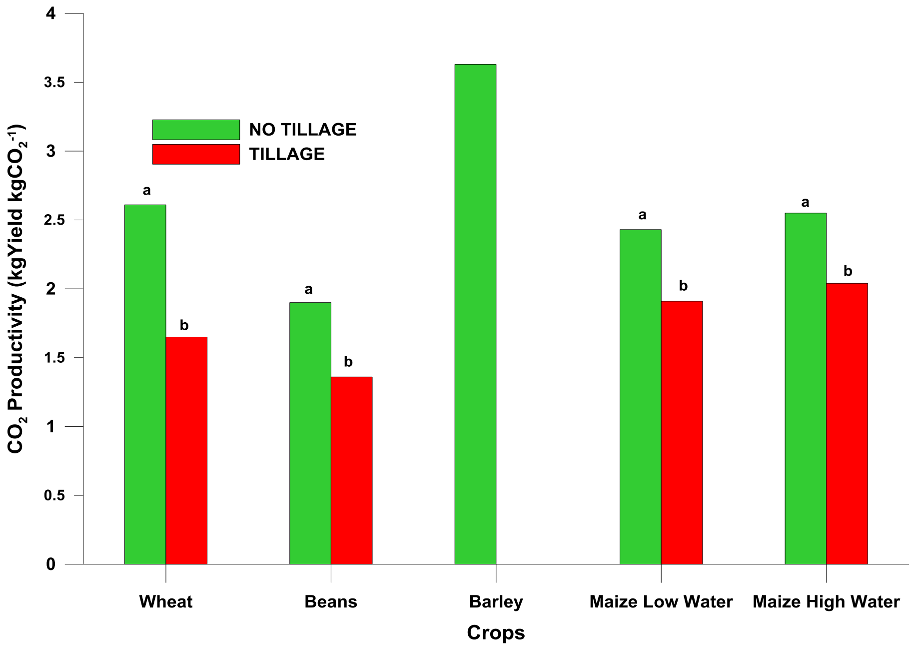

Figure 5. CO_2 productivity for the different crops and management studied. Different letters show statistical differences for Tukey Test p≤0.05.

4. Conclusions

The application of sustainable techniques as NT and GA have shown to be able to statically reduce the emissions of $CO_{2\ equivalent}$ to the atmosphere and improve its efficiency and productivity with different crops managed in rainfed and irrigated conditions. However, existed important differences between the results of the different crops and managements. For low used of fertilizers, no tillage brought the biggest reduction of emissions. In contrast, for high used of fertilizers, GA was more important. Most of the emissions came from the fertilization of the crops (more than 60%), not been the used of water as important as fertilizers. Despite these good results, it is necessary to have more years and crops studied, in order to obtained more robust results, especially important in the Mediterranean climate conditions, which are especially variable.

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