UNIVERSITÀ CATTOLICA del Sacro Cuore

DIPARTIMENTO DI POLITICA ECONOMICA

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Abstract

The rationale of this study originates in the multiple role that the primary sector plays in the global warming issue. On the one hand, the agricultural sector is the second major anthropogenic cause of global warming, on the other hand it is probably the sector that is suffering the most because of climate change (CC). Apparently however, it is also potentially part of the solution by means of a different, innovative, organization of its production process. Without incentives, profitability remains the real trigger for farming business to transition and implement different technologies from conventional agriculture. The purpose of this paper is to assess the double profitability - economic and environmental - of regenerative agriculture practices considering the new and old objectives of the sector.

Keywords: Climate Change, Regenerative Agriculture, Economic and Environmental Profitability; Soil Organic Carbon; GLS; Gross Profit Margin; DEA
JEL Classification: Q1, Q5, O3

1. Introduction

As the IPCC (2019) puts it, "scientific evidence for warming of the climate system is unequivocal". Overall, climate change is projected to have consequences on human health and on countries' national income, poverty and disadvantage through its impact on agriculture, industry, and tourism. The global climate change is identified by more than 90% of climate scientists to be largely a consequence of carbon dioxide (CO2) (and other green house gasses (GHG) measured in CO2 equivalents) emissions from human activity (Anderegg et al., 2010; Doran and Zimmerman, 2009); generally known as the anthropogenic origin of the climate problem. It is also acknowledged that the progression of the change is fast and the approaching of tipping points makes addressing climate change one of the most pressing issues facing the planet and human beings – the IPCC reports (2018) there is time for action for only another 12 years if we want to try and keep the increase in temperatures around 1.5°Celsius.

Multiple sectors and processes associated to human activities contribute to global GHG emissions, among which the primary sector is the second largest emitter. Total emissions from the agricultural sector have been growing exponentially since 1961 and now account for 18.4%[1] of direct GHG emissions[2]; rising to about one quarter when considering the food system as a whole (Climate Watch, The World Resources Institute, 2020). The source of a big part of the emissions from the primary sector is conventional modern agriculture: intensive high-input agriculture characterized by large monocultures and high-yield productivity maintained through a strong reliance on specific practices such as tillage, intensive use of synthetic fertilizers, pesticides, fungicides, insecticides, and herbicides. This system, brought about by the Green Revolution[3], has produced an unprecedented increase in agricultural production in the late 20th century; but this has come at the high price of burdensome negative externalities for the environment and for the sector itself. Actually, the indiscriminate intensification through plowing, flood-based irrigation, and the heavy reliance on synthetic fertilisers, has shown to have strong adverse effects on the quality and functionality of soil, water, air, vegetation, and biodiversity (Benson, 2014). Additionally, the decreased traditional use of manure to restore nutrients to the topsoil triggers a vicious circle where the subsequent loss of soil organic matter in turn affects soil structure and nutrient release, water retention and soil erosion, causing stagnation in agronomic production (Rahman & Zhang, 2018; Hofonga, 2018; Ussiri et al., 2019; Grassini et al. 2013) and eventually affecting the sustainability, resilience and profitability of farms (Schipanski et al., 2016).

Besides being a direct factor in GHG emissions, the primary sector suffers the adverse effects of climate change itself. Among others, in terms of higher temperatures, extended heat waves, flooding, shifting precipitation patterns, and saltwater inundation or intrusion of coastal fields. While individual events cannot be attributed to climate change, the change in the probability of such events can, and it is estimated that extreme summer temperatures—for example in Europe—are now 50% more likely to occur as a result of anthropogenic climate change (Stott et al. 2004). The long-term mean climate state impacts the nature of agriculture and farming practices (Gornall J. et al. 2010) and crop yield losses have been recorded where

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[1] Agriculture, forestry and land use

[2] Refrigeration, food processing, packaging, and transport

extremely high temperatures have prevailed (Zhao et al., 2017). Actually, change in growing season precipitation by one standard deviation can be associated with as much as a 10 % change in production (Lobell & Burke, 2008). Hence, under the projections of the global high emissions scenario (Seneviratne et al., 2012, IPCC), production is expected to decline, eventually putting at risk global food security (Gornall et al. 2010).

The concerns related to the primary sector are thus multiple. The sector is the second major contributor to CO2 emissions; it suffers soil degradation and itself the consequences of climate change, eventually in terms of decreasing yields (nutrient density of food is also affected) which contrast with the needs of a growing population[4] for which agricultural production per hectare[5] needs to increase (up to 70% according to FAO, 2015). As a resultant, the intensive agriculture that has been implemented since the first Green Revolution should no more be thought of as a sustainable and viable strategy.

However, there is a chance the primary sector can also be part of the solution. Relatively recent is the reception of an active role for the sector in the restoration of the offended environment and as a means to "buy time" in terms of environmental action[6]. This role refers to action beyond that of mere sustainability (i.e. no negative impact on the environment), which is no longer considered enough for addressing global CC effectively (WRI, 2021). In grand part this concretizes in C02 (and other GHG) absorbtion in the soil, the implementability of which is consequent to the soil Carbon (C) pool being 3.3 times the size that of the atmospheric C pool (760 Gt) (Lal, 2004; Paustian et al., 2016). Thus, soil has the potential to offset fossil-fuel emissions by 0.4 to 1.2 Gt C/year, i.e. 5 to 15% of the global emissions (Lal, 2019), signalling that even small changes in the soil C stock can have a strong impact on the atmospheric concentration of CO2 (Lal, 2020).

The process which allows soil to absorb CO2[7] is triggered by a set of specific restoring management practices which are referred to as Regenerative Agriculture (RA), but also Conservation Agriculture and sometimes Eco-Intensification (Lal, 2020), (we opt for RA). RA does not currently have a uniform scientific definition, but its scope can be summarised by means of its unifying principles, which are consistent across regenerative farming systems. These include: abandoning tillage, eliminating spatio-temporal events of bare soil, fostering plant diversity on the farm, and integrating livestock and cropping operations on the land (Rodale institute, 2021). In general, the goal of regenerative farming systems is restorative land use and site-specific best management practices, which conserve soil and water and strengthen elemental cycling (Lal, 2020) to increase soil quality and biodiversity in farmland.

Having said that, as Smith et al. (p.6, 2005) put it:

[4] of estimated 9.8 billion people by 2050

[5] not enough land remaining to be converted for agricultural usage to meet the additional demand for land resources also exacerbated by soil degradation (Oldeman, 1994; Tully, 2015).

[6] until the energy sector transitions to new sources

[7] All GHG are measured in CO2 equivalents for the sake of simplicity

"*GHG mitigation techniques will not be adopted by land managers unless they improve profitability, (…) measures are adopted for reasons other than for climate mitigation. Options that both reduce GHG emissions and increase productivity are more likely to be adopted than those which only reduce emissions.*"

Thus, in parallel with the environmental issue, yields and economic profitability need to be pursued by any new proposed agricultural system: both in light of the UN predictions on world population growth and of productivity and yields, one of determinants of the profit function of the farming business, the main actor in (the choice for) the implementation of RA. The key to crop production and yield sustainability is acknowledged to be soil quality; increasing soil organic carbon (SOC) and soil inorganic carbon (SIC) stocks – through soil carbon sequestration – triggers a virtuous process within the soil, eventually enhancing fertility and productivity (Lal, 2002). An increase of 1 ton of soil carbon pool in degraded cropland soils can increase crop yield by 20 to 40 kilograms per hectare (kg/ha) for wheat, 10 to 20 kg/ha for maize, and 0.5 to 1 kg/ha for cowpeas (Lal R., 2004). Table 1 reports selected findings from literature, relative to different world areas, on the performance of definite practices belonging to RA (often in the form of NT + cover crop + crop rotation) in comparison to conventional agriculture on staple-crop yields. In general, equivalent or increased yields are reported. These findings are in line with those in Pittelkow et al. (2015) who conducted a global meta-analysis to evaluate no-till relative to conventional tillage on staple crop yields.

Table 1. RA performance on Crop Yields

Author	Crop	Agri system	Performance on Yield (increase calcualted on average over conventional agriculture)	Performance on Soil Quality	CO2 retention measures compared to conventional	Location
Pradhan et al. 2018	Maize	Notill+ inter-croppping+ cover-cropping	200%	na	na	India
Wang et al. 2020	Spring Maize	No-till, Subsoiling	10%	>7% Soil Water Storage >18,4%Matter accumulation	na	China
Tian et al. 2016	Winter Wheat Maize	NoTill+ DeepTill	35%	na	>29-91%	China
Araya et al. 2015	Wheat with crop rotation	NoTill	>	>Soil Organic Matter		
Kinyumu 2012	Maize Beans	NoTill+ Cover Crop+ Crop Rotation	100%		na	Kenya
Rockstrom et al. 2009	Teff, Maize	NoTill	20-120%	>Soil Organic Matter	na	East Africa
Boselli et al. 2020	Winter Wheat Soybean	NoTill+ CoverCrop		>Soil Organic Matter		Italy

Hence, a "double profitability", environmental and economic, can be sought for as the new goal for the agricultural business. The purpose of this paper is thus to assess the environmental profitability (in terms of significance and timeliness) - here narrowed down to the (positive) impact on the environment by way of GHG absorbtion in the soil - and the economic profitability of RA with respect to Conventional Agriculture. RA is here implemented by means of no tillage (NT) in combination with cover cropping (CC), while conventional agriculture is implemented by conventional tillage (CT) and no cover cropping. The paper is organised as follows: section 2 introduces the data and methodologies used, section 3 displays a RA vs CT

SOC significance analysis, section 4 assesses a gross profit margin analysis, section 5 displays a DEA analysis, section 6 and 7 end with discussion and conclusions.

2. Data and Methodology

The research consists of a three fold analysis performed on a primary data panel gathered from a field experiment ran from 2011 to 2020 at the Centro Ricerche Zootecniche—CERZOO experimental farm in Piacenza (45° 00′ 18.0″ N, 9° 42′ 12.7″ E; 68 m a.s.l.), Po Valley, Northern Italy (Boselli et al., 2020); and a secondary data panel on crop prices gathered from the local Chamber of Commerce (Camera di Commercio Industria Artigianato e Agricoltura di Bologna, Italy, 2021). The RA and CT experiments were carried out within the research centre farm CERZOO (managed by the UCSC university) and on adjacent land plots, which allowed for the advantage of a controlled environment with all variables of interest taken account of. Thus, the main criteria for comparison such as geographical proximity, physical (soil composition) similarities, management and cropping type similarity are respected for (Nemes, 2009) and the biases which are recurring in this type of comparative analysis are overcome.

The field experiment was ran from 2011 to 2020 at the CERZOO experimental farm (45° 00′ 18.0″ N, 9° 42′ 12.7″ E; 68 m a.s.l.), in Piacenza, Po Valley, Northern Italy. The field study was established as a Randomized Complete Block (RCB) with four replicates (blocks) and two agro-ecosystem managements: on one side, conventional tillage (CT); on the other side no-till (NT) plus cover crops (CC) as RA system. Within each block, three experimental treatments as RA system were present: (i) NT plus rye (Secale cereale L.) as winter CC, (ii) NT plus hairy vetch (Vicia villosa Roth) as winter CC, and (iii) NT plus a 5-species mixture (rye 55%; hairy vetch 25%; crimson clover (Trifolium incarnatum L.) 8%; Italianrye-grass (Lolium multiflorum Lam.) 8%; and radish (Raphanus sativus L.) 4%) as winter CC. Full details on soil characteristics and experiment set up are reported in Boselli et al., 2020.

The cash crop sequence during the experiment was: (1) winter wheat (Triticum aestivum subsp. aestivum L.), (2) maize (Zea mays L.), (3) maize, (4) soybean (Glycine max L. Merr.), (5) winter wheat, (6) maize, (7) soybean, (8) winter wheat, and (9) maize. Therefore, CC were sown after harvesting the previous main crop when winter wheat (the crop cycle of which overcome the crop cycle of the selected cover crops) was not foreseen in the next place of the crop sequence (in details, between years 1 and 2, 2 and 3, 3 and 4, 5 and 6, 6 and 7, 8 and 9). Both cover crops and cash crops were direct drilled under the three RA treatments. Instead, the seedbed preparation under the CT treatment consisted of a conventional ploughing at 35-cm depth during fall season, and two rotating harrowing at 15–20-cm depths before seeding. Under RA treatments, the cover crop cycle was terminated in spring by spraying Glyphosate (2.4 L ha-1) and, two weeks after, the main crop was directly without chopping CC residues. Each plot was 22-m wide and 65-m long (1430 m2). All plots were tilled conventionally before starting NT management in 2011

During the 9-year experiment, data on grain yield of crops (Mg ha-1, at 14% kernel moisture content, which is the moisture reference for the price of crop grains), soil organic Carbon (SOC) storage (Mg ha-1, measured at 0-30 cm depth), and operational costs (Euro ha-1) were recorded for the four treatments. In detail, grain yield of crops was determined annually by manually harvesting three representative areas of 10 m2 per plot. Dry matter yield was obtained by oven-drying sub-samples at 105 °C until constant weight. Then, grain yield at 14% kernel moisture content was computed by dividing each dry yield by 0.86.

Soil samples were collected in each year after harvesting the cash crop. For each plot, 3 composite soil cores were collected randomly to a depth of 30 cm. Then, soil samples were air-dried, ground and sieved (2 mm mesh) before determination of SOC concentration (Nelson and Sommers, 1982). Soil bulk density (BD) was determined in the same sampling period for each year (on an additional set of samples) by dividing the oven-dry weight of each soil portion by its volume. Soil organic stock (Mg ha-1) was computed as the product of SOC concentration, BD and the 30-cm depth.

We assess:

1. the environmental profitability of RA by means of a statistical significance analysis of the difference between NT SOC levels and CT SOC levels related to time, i.e. when SOC values difference in CT and NT treated soils becomes significant relatively to time, (given that yields with NT + CC are found to be not significantly different from CT, (Boselli et al., 2020)
2. the economic profitability of the NT+CC -compared to CT- practices by means of a Gross Profit Margin analysis
3. the composite economic and environmental profitability of the NT+CC vs CT practices by means of a Data Envelopment Analysis (DEA)

To achieve the objectives of the study, statistical techniques and methodologies have been employed in the analyses of the data; including descriptive statistics, regression analysis, Gross Marginal Profit Analysis and Data Envelopment Analysis (DEA). Descriptive statistics, empirical models, analysis of gross profit margin and DEA were run on Excel and R computer software.

3. Significance Analysis

The rationale of this analysis is the assessment of the timeliness of the impact of the activities implemented to counter climate change - in our case the impact of NT+CC on SOC. Thus, given Boselli et al. 2020 report positive impacts of NT+CC on SOC in comparison to CT; we want to assess if and after how long the difference in terms of the impact on SOC between the two systems (NT+CC and CT) becomes significant. The study comprised n=3 crops: winter wheat, maize and soybean; NT+CC and CT treated plots in the time frame of 2011-2020.

A box and whiskers plot (figure 1) and a generalized least square (GLS) regression (1), with heteroskedacticity correction, were performed in order to quantify the impact of SOC absorbtion consequent to the RA management. The regression model explains the level of SOC as a function of the years from the transition from CT to NT:

$$Log(SOC)_{i,t}=\beta_0+\beta_1 year_t+ \beta_2\, NoTill+\beta_3 Soy_{i,t}+\beta_4 Wheat_{i,t}+\beta_5 year_{i,t} \times NoTill_{i,t}+e_{i,t} \qquad (1)$$

In the regression equation (1) the dependent variable is the Log(SOC), the explanatory variables are:

- $year_t$ - the years since the plot has transitioned from T to NT+CC (i.e. from conventional agriculture to RA),
- $NoTill_{i,t}$ - the dummy variable that distinguishes between a T treated plot and a NT treated plot,
- $year_{i,t}$□$NoTill_{i,t}$- the slope dummy which captures the impact of the interaction between the years of NT and the crop,
- Main $Crop_{i,t}$ - the control variable, since it is a cathegorical variable with three levels (soybean, maize, wheat i.e. the type of crop), we used two dummy variables ($Soy_{i,t}$, $Wheat_{i,t}$)
- $e_{i,t}$ is the error term.

3.1 Results (Significance Analysis)

The impact of NT + CC and Till (T) + crop residue management on the Soil Organic Carbon (SOC) level in the considered time frame (2011-2020) are shown in the Whiskers Boxplot diagram in figure 1. The descriptive distribution exhibits the impact of CT (=0 in the diagram), on SOC levels as constant in the observed time frame (2011-2020), and the impact of NT (=1 in the diagram) on SOC as constantly increasing. In particular, we can observe that after the 3rd year the upper whisker relative to the CT is lower than the lower whisker of the NT.

Figure 1. SOC levels in Till (0) and NoTill (1) related to time

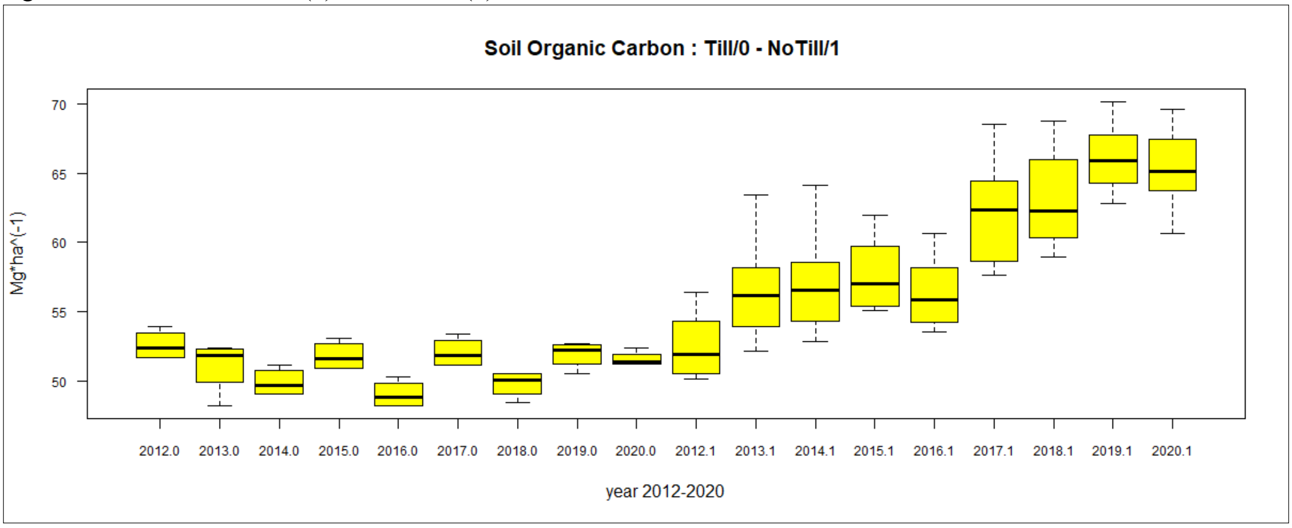


Table 2. GLS Coefficients

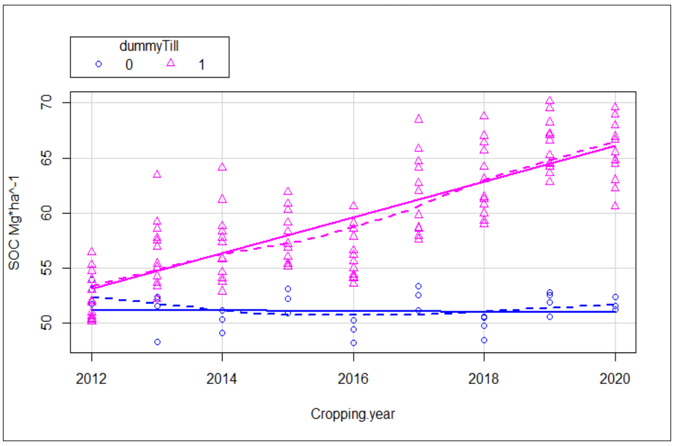
	Estimate	Std. error	t value
Intercept	-50.49	0.6158	-81.998***
Cropping.year	0.02708	0.0003	88.697***
DummyNoTill	55.38	0.8465	65.424***
Main.Crop==Soybean	-0.01128	0.0017	-6.497***
Main.crop==Wheat	-0.01923	0.0015	-13.005***
Cropping.year:dummy NoTill	0.0275	0.0004	-65.628***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 1.008 on 138 degrees of freedom
Multiple R-squared: 0.9958,
Adjusted R-squared: 0.9956
F-statistic: 6489 on 5 and 138 DF,
p-value: < 0.0001

The GLS regression results (table 2) highlight a significant improvement of the coefficient of the variable 'cropping year' (0.0275) when transitioning from Till to NoTill ceteris paribus: the average level of the Log(SOC) increases significantly in the transition fron Till to Notill, all else equal. We verified for the necessary linear regression assumptions: residuals have null mean (t test, p value= 0.8549), do not deviate from normality (Shapiro test, p value= 0.2122) and do not deviate from homoskedasticity (White test, p value=0.7392).

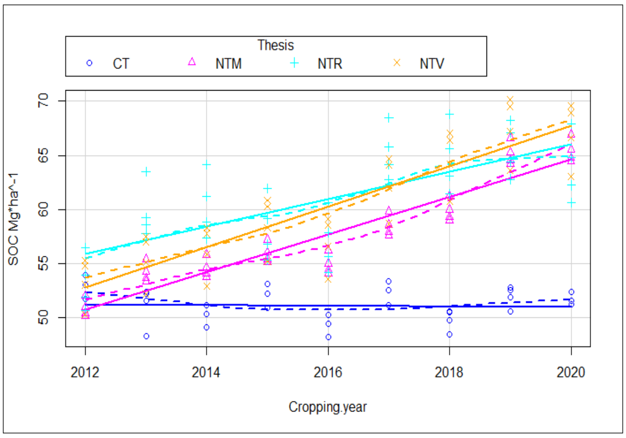
Graph 1. Linear Trend of Till and Aggregated NoTill impact on SOC levels 2011-2020



Further, Graph 1 highlights the linear trend of Till and aggregated NT+CC impact on SOC levels, consequently a comparison of the slope between CT and NT+CC on SOC can be drawn.

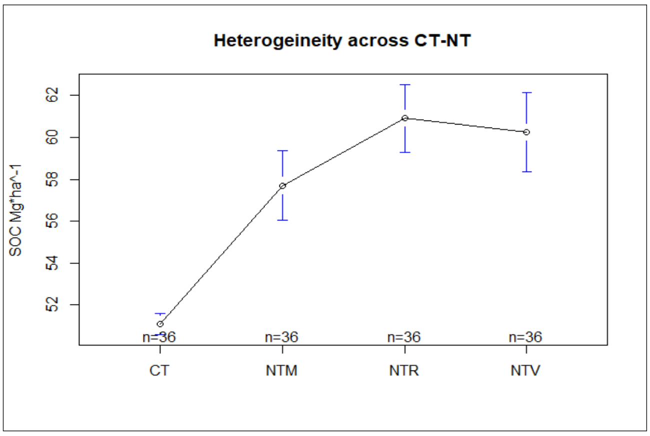
Graph 2 highlights the impact of NT+CC on SOC but differentiating per covercrop (Mix, Rye and Vetch). There is no significant difference in the impact on SOC dependent on cover crop type: the trend is increasing for all three covercrops.

Graph 2. Till (CT) and Disaggregated NoTill (NT) + Cover Crop (Mix, Rye, Vetch) impact on SOC levels



Graph 3 analyses the variability of SOC levels per NT+CC and CT systems. SOC remains constant in the considered time frame for CT production, while it has a greater variability in NT practices (NTR, NTM, NTV), the levels of SOC are significantly greater under NT (+CC). Actually the lower end of the confidence interval of the average value of SOC for the disaggregated NT + CC is greater than the upper end of the confidence interval of the average value of SOC for the CT.

Graph 3. Heterogeneity across NT and T practices on SOC.



4. Gross Profit Margin Analysis

The rationale of this analysis is that SOC absorbtion is to date considered a positive externality and a public good without a market. Thus, in the absence of market incentives, the only incentive for a farming business to transition to a RA management is the relative attainable profitability. Hence, we compare the economic profitability of CT and RA land management by means of a Gross Profit Margin analysis, which is generally used to determine the level of farm profitability.

Any differences in crop yields and their correlation to SOC levels for the two systems (CT and NT) have been accounted for in Boselli et al. 2020. However, yields are not per se a characteristic of a production system, and alone do not indicate farm profitability which additionally depend on farm management and production costs. These include operating costs (volume related costs) and fixed costs i.e. business costs not dependent on the external inputs level. Given that the experiment is run on the same farm and that RA does not need specific hardware investments, fixed costs are the same for CT and RA. Thus, we can consider exclusively variable costs in our calculation of the Gross Profit Margins for the conventional agriculture managed plots (CT) and for the RA managed plots (NT+CC).

Moreover, while it occurs that different crop varieties influence the whole rotation (and possibly market prices), this is overcome here since the same varieties are grown both on the NT plots and the CT plots, which are within the same farm and display the same type of soil. We applied average yearly crop prices taken from the Camera di Commercio Industria Artigianato e Agricoltura di Bologna.

Gross Profit Margin was calculated as:

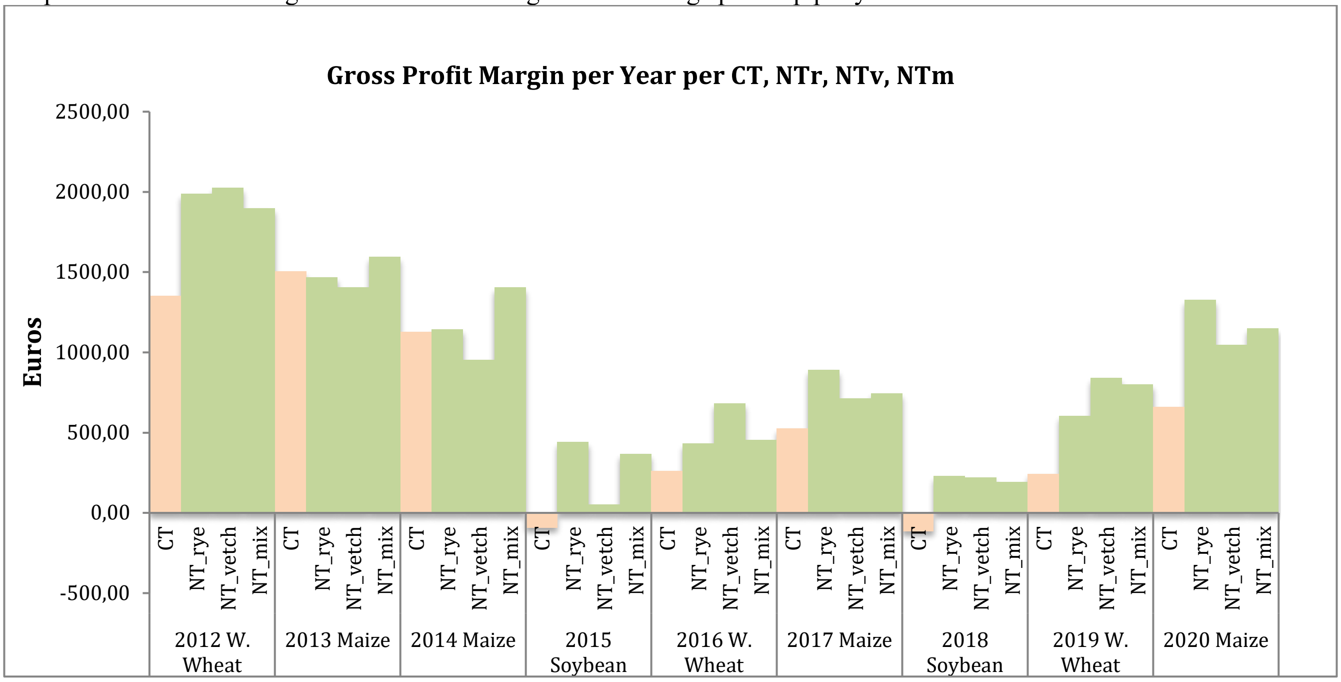
$\text{Gross Profit Margin}_i = \text{yield/ha}_i \times \text{price/tonne} - \text{operational costs}_i$

$i = T, NT$

4.1 Results of the Profit Margin for CT and RA

Graph n.4 exhibits the results of our Gross Profit Margin analysis per year. The graph highlights that NT + CC managed rotations generally consistently outperform CT managed plots in a range from 6% to 200% in terms of gross profit margin. This is particularly manifest for winter wheat and soy. Only the maize rotation exhibits a slower adaptation to the transition form CT to NT+CC. For the first two maize rotations (2013, 2014), CT management exhibits a higher gross profit margin - in particular for the combination of NT + hairy vetch- but for NT+ mix which outperforms CT by 6% in 2013 and by 24% in 2014. The displayed impact on the gross profit margin derives exclusively from variations in yields (which result not significant, see Boselli et al. 2020) and relative management (NT+CC, CT) operational costs[8], since all other variables are equal as are the crop varieties grown in the NT and CT plots and hence, their relative selling prices.

Graph 4. Gross Profit Margin Conventional Tillage and NoTillage per crop per year



5. Data Envelopment Analysis

Finally, we assess the composite (economic and environmental) effciency of the CT and NT+CC farm managements. No tillage + covercrop (NT+CC) can be included among technological changes. In fact, it can be defined as a disembodied technological change: it constitutes of a different way of combining inputs or using existing resources, it is a change in production technology (FAO, 2018). This makes it suitable to be measured with the Data Envelopment Analysis (DEA) method (Charnes et al. (CCR), 1978; Farrell, 1957), which is commonly applied to the agricultural sector (Atici & Podinovski, 2015; Cucchiela et al., 2018; Fogarasi & Latruffe, 2009; Latruffe & Desjuex, 2016; Malana & Malano, 2006; Odeck, 2009; Parlinska & Bezet, 2010; Syp et al., 2015; Toma et al., 2015; Toma et al., 2017; Vasiliev et al., 2008).

DEA consists of a nonparametric linear programming model for measuring the efficiency of a decision making unit (DMU) relative to other DMUs, on the basis of multiple inputs and outputs. The objective of DEA is to assess the relative efficiency of units which are comparable. The result of this analysis typically brings to the fore a 'best practice' frontier. The model has two alternative orientations: input or output DEA (Charnes, Cooper, & Rhodes, 1978). For the pruposes of this analysis, the Output-oriented DEA is best suited [9]: it singles out the unit which produces the highest level of outputs from a given combination of inputs. Following Roll et al. (1991) the DMUs for the DEA evaluation need to be defined and selected considering the boundaries that affect their determination. These are 1) organizational, physical or regional boundaries which define the individual units, and 2) time related boundaries: the time periods applied in measuring the activities of the DMUs should be "natural", i.e. corresponding to seasonal cycles, budgeting or

[9] However, Coelli et al. (2005) noticed that outcomes from both models are comparable, therefore, the choice of orientation is not crucial.

auditing periods. In our case the organizational or physical boundaries are overcome since the evaluated DMUs belong to one farm (CERZOO), which avoids potential differences in physical or organizational terms and satisfies the requested homogeneity. Further, though we have a panel data set, we opted for a yearly cross-section analysis, following the natural cycle of crops and the crop change per cycle. We have thus identified four DMUs: CT (conventional agriculture management), NT rye (regenertive agriculture + cover crop= rye), NT vetch (regenertive agriculture + cover crop= vetch), and NT mix (regenertive agriculture + cover crop= mix). These comply to the requested characteristics of being a 'homogeneous' set of decision making units where comparison makes sense. Further, we determined the input and output factors which are relevant and suitable for assessing the relative efficiency of the selected DMUs. The input factors must be selected such that they accentuate the basic differences among units. We consider operational costs per DMU as the input factors. The output factors are the gross profit margin, which represents economic profitability, and the level of SOC which represents environmental profitability.

Efficiency is then measured with respect to the DMUs and factors selected, identifying the differences in performance. The chosen performance measures reflect the efficiency of each DMU in terms of economic and environmental profitability. The software used for the calculations is R.

5.1 Results (DEA)

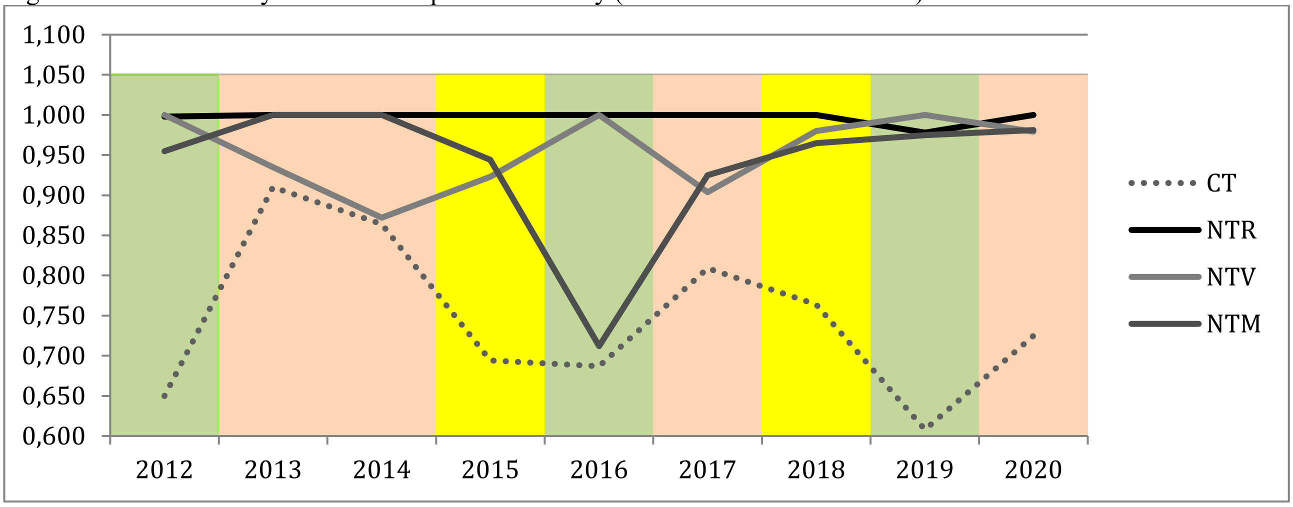
Table 3 displays the results of the DEA analysis. At the aggregate level the NT+CC units are more efficient in terms of the assessed composite efficiency. At a disaggregated level, NTrye represents, except for 2019 (i.e. for winter wheat), the frontier of maximum efficiency from which the frontier of values for the CT unit is clearly detached. The least distance between CT and NT efficiency frontiers is displayed for maize, but only in the first two rotations as can also be seen in graph n.5. Instead, the distance between the CT performance and the NTrye or NTvetch best practice is accentuated for the winter wheat rotation. NT therefore represents an aggregate best practice and cover crops have different impacts depending on the crop; recalling that RA is a site-specific strategy.

Table 3. DEA analysis results on composite efficiency (economic & environmental)

	2012	2013	2014	2015	2016	2017	2018	2019	2020
CT	0,65	0,91	0,86	0,69	0,69	0,81	0,76	0,61	0,73
NTR	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,98	1,00
NTV	1,00	0,94	0,87	0,92	1,00	0,90	0,98	1,00	0,98
NTM	0,96	1,00	1,00	0,94	0,71	0,93	0,97	0,98	0,98

CT- Conventional Till; NTr- NoTill rye, NTv- NoTill vetch, NTm- NoTill mix

Figure 5 & 6. DEA analysis results composite efficiency (economic & environmental)



6. Discussion

In this paper we compared Regenerative agriculture (RA) and Conventional agriculture (CT) agricultural land management in terms of the timeliness of Soil Organic Carbon absorbtion, economic profitability and composite efficiency (environmental and economic) per system. This is accomplished by means of a three-fold analysis - a regression analysis, a gross profit margin analysis and a Data Envelopment analysis on panel data from a comparative field experiment.

The results of the analyses in general exhibit a positive comparative response for RA. In particular, the RA managed plots promptly register an increase in Soil Organic Carbon (SOC) levels; they result comparatively economically profitable from the first year of implementation for two crops out of three with the third crop picking up soon after (in the second and third rotation); and they emerge as the best practice in terms of composite efficiency (economic and environmental).

The interest of this study lies in the relative multiple points at issue. To begin with, the analysis on the timeliness of SOC absorption is of interest with respect to the stringent deadlines given by scientists – by the time of writing, only 10 years to implement actions to combat climate change in order to keep the temperature increase at 1.5°C (IPCC, 2018). Hence, it provides a rationale for decision-making when comparing with other possible land management practices to fight climate change; such as reforestation, which has a much slower impact time (40 years) than RA land management (Bateman, 2009). Potentially it is also of interest for decisions related to the carbon credit market, in the event that payments are defined above a certain threshold of SOC absorption.

The second analysis takes into account that farming is a business and as such it pursues a profit, which makes the comparative economic profitability of the RA management of plots foundational. The assessment of the economic profitability also provides for the risk aversion that characterizes farmers, makes them conservative and prevents them from picking up new technology (AIMIN, 2010). In the absence of incentives for a transition to RA, economic profitability is pivotal in the decision of the farmer to adopt this land management.

Finally, the composite efficiency analysis asesses the double profitability (environmental and economic) of Regenerative agriculture vs Conventional Agriculture bringing out the potential of RA as a new business paradigm, particularly in the agricultural sector. Indeed, the results of this analysis distinguish RA as a best practice in environmental and economic terms. The policy implications here are manifold. For example for the formulation of agricultural policies: in the EU the new Common Agricultural Policy (CAP) proposes sustainable agriculture as one of its objectives and is in the process of being reformed (the new CAP is due in 2023). Hence, the CAP has the opportunity to review the direction of its substantial subsidies to agricultural production and accelerate the transition to RA. This would also mean straightening out the inconsistency in the CAP regarding the use of public money for the production of private goods (subsidies to production), and reshaping it into subsidies to the production of a public good (SOC absorbtion, for example): *"public money* for *public goods"* (p. 297, Bateman, 2018).

However, the relevance of this analysis goes beyond the CAP, since World agricultural land area is approximately five billion hectares, 37% of the global land surface, and about one-third of this is used as cropland (WB, 2018). For example, RA could be implemented in 43% of the EU area and 44% of the US agricultural land. In particular, the results of this study combined with others[10], show that developing countries are potentially primary actors in the fight against climate change, with additional positive spillovers on poverty.

7. Conclusions: what to do next

Despite the substantial potential, the transition to RA is not easy to implement. This is apparent if we think of the fragmentation of the world agricultural land. In the EU alone, the land devoted to agriculture is fragmented into 10.5 million agricultural holdings, two-thirds of which are less than 5 ha in size (EUROSTAT, 2016), while in the US the number of farms in 2019 was estimated at 2,023,400, even though the average farm size is 180 ha (NASS, 2020); not to mention developing countries, where the size of farms is around 1–1.5 hectare in Africa and even less in Asia. Moreover, and in developing countries particularly, there is a lack of the necessary institutions to disseminate the RA related know-how. Additionally, sociological, economical and political restraints are generally reported (Paustian et al., 2016; Amundson et al., 2018).

So what are the strategies and policies to be implemented to allow this virtuous transition to come true? Implementing both top-down and bottom-up interventions will potentially achieve better and faster outcomes. To begin with, taking action on the carbon credit market so as to raise the price paid for C sequestration, rather than just raising C taxes. This should become a significant part of the farmers' production function and thus act as an incentive to transition to RA. Higher prices for C sequestration would also have a welcome buffer effect on the volatility of agricultural production concurrently addressing the mentioned high risk-aversion in farmers relative to new production techniques (Aimin, 2010). Preliminarily,

[10] See, e.g., Pittelkow (2015), who carry out a meta-analysis that reports an improvement in the resilience of territories (particularly in degraded or arid areas) subject to RA management, in addition to matching or higher yields.

the necessary technology for C sequestration measurements needs to become standardized and systematic in order to guarantee space-time comparability.

In addition to the Carbon Credit market instrument aiming at triggering the transition bottom-up, the change must also be encouraged from above. This would imply the revision of agricultural policies, considering public support for the production of this public good that farmers provide while producing private goods. Furthermore, since C sequestration is a *global* public good, developed countries could extend carbon credit markets and the relative payments outside their borders, comprising developing and least developed countries also possibly by partly redirecting and replacing existing heterogeneous aid measures. Finally, RA should be implemented in urban areas also, in order to counter the negative effect of heat islands (Heaviside et al. 2016) and pollution.

All in all a change in the paradigm is needed and it is high time for a double profitability, both economic and environmental, to be encouraged, so as to make ends meet between the "thinking of the end of the world" of scientists and scholars, and the "thinking of the end of the month" of agricultural entrepreneurs, the main actors in the called-for transition.

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